DEPARTMENT OF THE ARMY
DEPUTY UNDER SECRETARY OF THE ARMY
OPERATIONS RESEARCH
102 ARMY PENTAGON
WASHINGTON DC 20310-0102

17 MAR 2000

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Army Guidelines on the Use of Models and Simulations (M&S) in Support of Test and Evaluation (T&E)

As a result of the Project Manager and Test Community Interaction Process Action Team (PAT) that I formed last year, eleven of the thirty recommendations developed were selected for implementation.

Enclosed are the subject guidelines that I hereby provide for your use. I encourage each of you to widely distribute these guidelines within your organization. A copy of the guidelines can be obtained from the U.S. Army Test and Evaluation Management Agency web site - http://www.hqda.army.mil/tema.

Walter W. Hollis

Encl

Walter W. Hollis
Deputy Under Secretary of the Army
(Operations Research)

DISTRIBUTION:
Commander, U.S. Army Materiel Command, ATTN: AMCRDA, 5001 Eisenhower Avenue, Alexandria, VA 22333-0001
Commander, U.S. Army Space and Missile Defense Command, ATTN: SMDC-SP-I, Box 15280, Arlington, VA 22215-0280
Deputy Commander, U.S. Army Space and Missile Defense Command, ATTN: SMDC-RM/SMDC-KMR, Box 1500, Huntsville, AL 35807-3801
Program Executive Officer, Air and Missile Defense, 215 Wynn Drive, Huntsville, AL 35805-3402
Program Executive Officer, Aviation, Bldg 5681, Room 160, Redstone Arsenal, AL 35898-5000
Program Executive Officer, Command, Control and Communications Systems, Myer Center, Room 3C109, Fort Monmouth, NJ 07703-5000
Program Executive Officer, Ground Combat and Support Systems, Bldg 171, Picatinny Arsenal, NJ 07806-5000

Program Executive Officer, Ground Combat and Support Systems, 6305 Eleven Mile Road, Warren, MI 48397-5000
Program Executive Officer, Intelligence, Electronic Warfare and Sensors, Myer Center, Room 3D121, Fort Monmouth, NJ 07703-5000
Program Executive Officer, Standard Army Management Information Systems, 9350 Hall Road, Suite 142, Fort Belvoir, VA 22060-5526
Program Executive Officer, Tactical Missiles, Bldg 5250, Room A200, Redstone Arsenal, AL 35898-8000
Project Manager, Instrumentation, Targets, and Threat Simulators, 12350 Research Parkway, Orlando, FL 32826-3276
Project Manager, Instrumentation, Targets, and Threat Simulators, National Capital Region Liaison, 13873 Park Center Road, Suite 500, Herndon, VA 20171

CF:
Commander, U.S. Army Test and Evaluation Command, ATTN: CSTE-CG CSTE-PM, Park Center IV, 4501 Ford Ave., Alexandria, VA 22302-1458
Director, Army Materiel Systems Analysis Activity, ATTN: AMXSY-B/AMXSY-S, 392 Hopkins Road, Aberdeen Proving Ground, MD 21005-5071
Director, Army Research Laboratory, ATTN: AMSRL-SL, Aberdeen Proving Ground, MD 21005-5068

Guidelines:

Use of
Modeling and Simulation (M&S)
to Support
Test and Evaluation (T&E)

April 18, 2000

U.S. Army Test and Evaluation Management Agency
200 Army Pentagon
Washington, D.C. 20310-0200

TABLE OF CONTENTS

TABLE OF CONTENTS

Guidelines - Use of Modeling and Simulation (M&S) to Support Test and Evaluation (T&E)

Section I
Overview

1. Purpose/Scope.

a. The purpose of this document is to

(1) establish guidelines for the integration of M&S into T&E, in support of the acquisition process.

(2) provide examples of effective use of M&S in support of T&E.

b. Department of Defense (DoD) Policy

(1) DoD Regulation 5000.2-R, paragraph 3.4.4 states:

Accredited models and simulations (M&S) shall be applied, as appropriate, throughout the system life-cycle in support of various acquisition activities: requirements definition; program management; design and engineering; efficient test planning; result prediction; and to supplement actual test and evaluation; manufacturing; and logistics support. PMs shall integrate the use of modeling and simulation within program planning activities, plan for life-cycle application, support, capitalizing on reuse of models and simulations, and integrate modeling and simulation across the functional areas.

(2) DoD Directive 5000.59 (DoD M&S Management, Section D, Policy states:

The DoD Components shall establish verification, validation, and accreditation (VV&A) policies and procedures for M&S applications managed by the DoD Component. The "DoD M&S Executive Agent" shall establish VV&A procedures for that application.

M&S applications used to support the major DoD decision-making organizations and processes (such as the Defense Planning and Resources Board; the Defense Acquisition Board; the Joint Requirements Oversight Council; and the DoD Planning, Programming, and Budgeting System) shall be accredited for that use by the DoD Component for its own forces and capabilities.

c. Scope.

(1) M&S are always considered to support the developmental test, operational test, and evaluation/assessment of systems as they proceed through the life cycle. The abbreviation "M&S" throughout these guidelines is used to represent model(s), simulation(s), simulator(s), or model(s) and simulation(s). Simulators include emulators, drivers, and stimulators that are used to fully work load a system under test are also included.

(2) Use of M&S will include, but not be limited to, the identification of test parameters and drivers for field tests; determination of high risk areas; prediction of test results; assisting in the allocation of scarce T&E resources; and the assessment of system capabilities in situations which cannot be tested due to safety, cost, or other constraints.

Section II
Background

2. General.

a. This paragraph provides background on the use of M&S to support or supplement T&E. Testing is conducted to support comprehensive and effective evaluations in support of Army system acquisitions. Credible evaluations are required to support decision-making within the acquisition process. Tests and evaluation are interrelated and complementary processes. Both are necessary; however, neither process alone is sufficient. Evaluations judge overall system effectiveness, suitability, and survivability based, in part, on technical and operational requirements while reassessing as the system evolves. Test results, among other credible sources of data such as M&S, are an integral part of the system evaluation.

b. M&S have been used extensively to support the weapon development T&E process that includes the software development T&E process. Army systems in development are increasingly complex. Testing of such systems can be large in scope and require conditions that are difficult, if not impossible, to duplicate short of actual combat. The practicalities of cost, test range space, availability of advanced threat systems/surrogates, and safety will necessarily limit test planning and test data availability. M&S can address such limitations. System evaluation may require an M&S to integrate available test data so as to extrapolate or interpolate (See Appendix C, paragraph 3.b) to those conditions that could not be tested due to constraints and limitations in the test environment. While M&S are not a replacement for testing, they are complementary tools to assist in the system evaluation process.

3. SMART. The Simulation and Modeling for Acquisition, Requirements and Training (SMART) concept more closely integrates the efforts of the requirements, acquisition, and training communities through the use of M&S. It fosters collaboration among the three communities by integrating M&S starting early in the acquisition process, creating a large trade space among performance, cost, design, manufacturing, supportability, and training, with the ultimate result of providing systems with greater utility, lower cost, and less burden on the operations and sustainment budget. Planning for SMART involves developing a M&S strategy that is an interconnected part of the overall acquisition strategy for a system. Documenting the M&S strategy in a Simulation Support Plan (SSP) enables the necessary continuity as the system matures through its life cycle. Having the M&S used in support of T&E, also documented in the SSP, ensures that the combat developers, trainers, materiel developers, testers and the evaluator (to include the independent logistician) have sufficiently thought through the benefits, costs, opportunities, and schedule considerations associated with the use of M&S. By developing and documenting a plan (in this case the developing TEMP being cross referenced with the SSP), allows insight by the collaborative team into what M&S is being executed around them, thereby, enabling them to leverage existing investments. The SSP is intended to provide the Program Manager a tool to use in thinking through M&S requirements throughout the system's acquisition life cycle and assist in developing a strategy for using M&S that will ultimately result in an acquisition strategy that incorporates SMART to reduce time, resources, and risk as well as improve program implementation.

4. M&S Use Documented in the Test and Evaluation Master Plan (TEMP) and Simulation Support Plan (SSP).

a. Planning for a system's evaluation usually involves a trade-off analysis that identifies the appropriate, affordable, and credible data sources (e.g., M&S, DT, and OT) to answer the system's Critical Operational Issues and Criteria (COIC) and Additional Issues (AI), based upon the system's critical technical parameters, Operational Requirements Document (ORD), and other requirements. During the T&E planning process, testers and the evaluator determine to what degree M&S are necessary to supplement other credible data sources. Additionally, the System Evaluation Plan (SEP) establishes the complementary roles that M&S and testing will play to support the analytic process.

b. The extent of M&S use, whether an existing M&S or newly developed M&S, in conjunction with T&E will be documented in the system's required Test and Evaluation Master Plan (TEMP) and cross-referenced with the program's Simulation Support Plan (SSP). M&S types, their applications, and their resource requirements are also documented in the TEMP. All users of M&S must accredit the M&S for a particular use. Accreditation will be based upon the extent of V&V associated with the M&S. M&S accreditation is especially essential prior to extrapolating, interpolating, or predicting system performance (including software, hardware, man-in-loop) (See Appendix C, paragraph 3.b). M&S verification, validation, and accreditation (VV&A) status, along with the degree to which M&S will augment test data to assist in system evaluations and assessments, is also documented in the TEMP.

c. Special attention should be given to the validation of threat that is in M&S. The Army Threat M&S Development and Validation Process, along with DoDI 5000.61, establish procedures for the identification, development, validation, and accreditation of "Red/Grey" threat products.

5. Model-Test-Model (MTM) Process. A disciplined test process flows from developing test requirements, to pre-test analysis/test design, test conduct, data processing, post-test analysis/evaluation, and testing feedback. Figure 1 depicts three applications of the two types of M&S – engineering and combat.

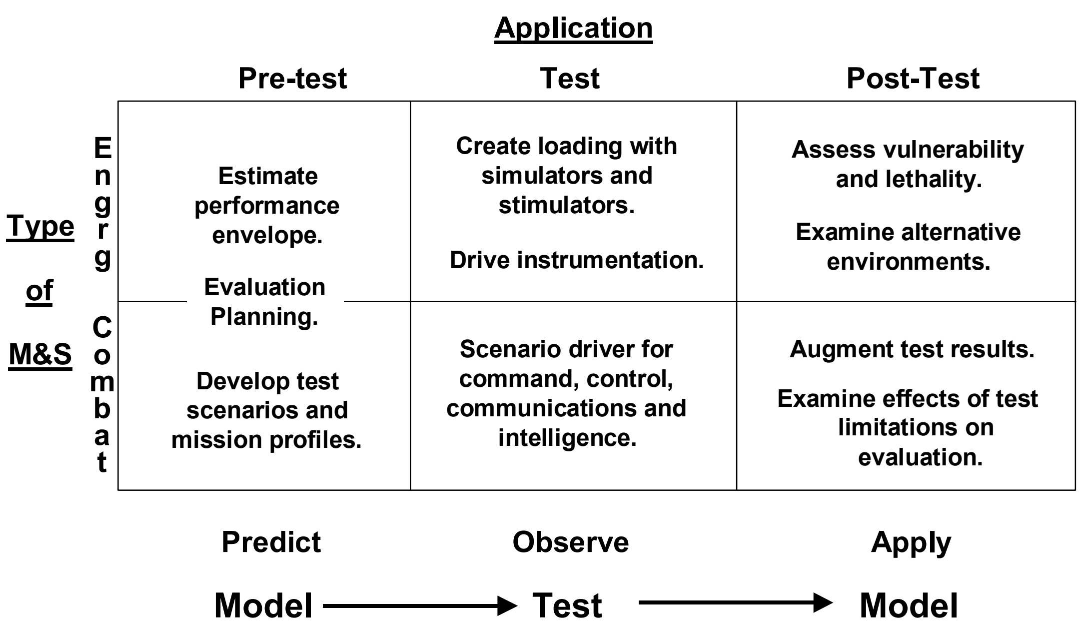


Figure 1. Examples of M&S Applications in a Model-Test-Model Process.

6. Why Apply M&S to T&E. Test and evaluation are discrete but complementary processes. Both are essential to the acquisition decision cycle since neither provides sufficient information on its own.

a. Evaluations judge overall system performance against technical and operational mission requirements and reassess performance as the mission requirements and system designs evolve. Test results, among other sources of information, are an integral part of the evaluation. M&S tools can assist the evaluation process. A consistent and traceable set of tools should be used throughout the T&E process to help mitigate surprises encountered during testing or by analysis of test results.

b. Similarly, validated and accredited M&S can be used interactively to dynamically drive testing. Threat M&S can be particularly valuable in this regard. For example, M&S can be used to drive hardware-in-the-loop environments, maintenance procedure testing, and perform software verification and validation. Virtually integrated threat hardware or virtual threat M&S can dynamically drive operational test scenarios to achieve realistic, data rich evaluation environments. Moreover, the existence of validated M&S could potentially reduce the breadth and associated cost of operational testing.

c. Whatever the T&E application, M&S will continue to be used extensively. Army weapon systems have become increasingly complex. BLUE systems are required to operate in adverse environments. They are also required to interact with other BLUE systems over extended ranges. Consequently, development of advanced command and control (C^4I) systems are required to overcome these difficulties. Extensive testing of integrated systems premises duplication of multiple conditions that are difficult if not impossible to create---short of actual combat. The practicalities of cost, range space, availability of advanced threat systems, safety, etc., will necessarily limit testing. Application of M&S provides a venue to address such limitations. Evaluation of a major system's performance may, for instance, require a "model" to integrate the available test data and to extrapolate those conditions which cannot be achieved due to test constraints (See Appendix C, paragraph 3.b). Such models and simulations are not replacements for testing. Rather, M&S complements the T&E process.

7. Types of M&S Used.

a. M&S is the development and use of live, virtual, and constructive models to investigate, understand, or provide experiential stimulus to either conceptual systems that do not exist or real life systems which cannot accept experimentation or observation because of resource, range, security, or safety limitations. This investigation and understanding in a synthetic environment will support decisions in the domains of Research, Development, and Acquisition (RDA) and Advanced Concepts and Requirements (ACR), or transfer products, tools, and information in the Training, Exercises, and Military Operations (TEMO) domain.

b. The Army uses a wide range of M&S types in the T&E process, including, but not limited to:

(1) engineering models (i.e., those that emulate every steering command sent to the control mechanisms of guided weapons, those that provide six-degree of freedom representations of weapon trajectories, those that address countermeasures by taking into account propagation characteristics of the atmosphere as well as target susceptibilities);

(2) hardware-in-the-loop simulations (i.e., those involving a marriage of developmental hardware and software and other equipment or stimuli with which the developmental system must be able to interact or function on the battlefield);

(3) battlefield environment models (i.e., those that represent natural and man-made aspects such as smoke, dust, and obscuration, those that estimate terrain effects on system mobility characteristics, those that estimate one-sided performance of a system, those that predict reliability and those that address supportability issues);

(4) combat models (i.e., one versus one models, such as duels between weapons or jammers against radars, force-on-force models, ranging in force size from several elements on each side to the corps level); and

(5) computer aided design and computer aided manufacture (CAD/CAM).

c. Engineering level models are generally one-sided.

(1) The effectiveness of a new tank may be characterized by representing its target acquisition and firepower capabilities versus threat tank attributes such as signature, size, speed, maneuverability, and protection. Turning the one-sided model around and estimating the threat tank capabilities against the new tank attributes might examine the survivability of the new tank.

(2) Engineering level/sub-system automotive performance models consider engine horsepower, vehicle weight, vehicle weight distribution, traction, and other attributes along with terrain characteristics to examine mobility.

(3) Synthetic battlefield environments (for example, the MILES system) are used in training exercises and operational tests that use weapon-target effectiveness estimates (Pk's) to predict the attrition. Engineering level performance models generate these effectiveness estimates.

An item level model can draw upon engineering models for input, and it can then provide input to the lower resolution models in the hierarchy described above (i.e., duels and force-on-force).

d. Analyses and evaluations that support the acquisition process may include the use of force-on-force models that assist in the evaluation of the synergistic aspects of a developmental system's contributions to total force effectiveness. A force-on-force M&S example is the Battle Command Identification System (BCIS). BCIS is an IFF system for major Army vehicles, to reduce fratricide. The BCIS T&E strategy uses a mix of tests and M&S as data sources to evaluate how well BCIS performs under various environmental conditions (e.g., smoke, rain, electronic jamming), and the extent to which BCIS actually reduces fratricide rates. BCIS performance accuracy will be tested under a select set of environmental conditions. The results will be fed into the BISEPS model, which will interpolate the performance accuracy under a much larger set of conditions. Weapon system response time with BCIS will be measured during operational testing (OT). The BCIS OT response time results and the performance parameters from BISEPS will be fed into the CASTFOREM combat model to measure the influence of BCIS on fratricide rates. Measuring the influence of BCIS on fratricide rates without the BISEPS and CASTFOREM models would require a vastly increased time and scope of testing and would also require a vast increase in test instrumentation. Using these models also allows a sensitivity analysis that relates degrees of performance accuracy and weapon response time degradations to potential changes in fratricide rates.

Section III
M&S Applications in T&E

8. General M&S Applications to T&E. Table 1 provides an overview of M&S applications in support of T&E. The following paragraphs provide additional details.

a. Support Evaluation/Test Design Planning.

(1) M&S can assist in the T&E planning process and can reduce the cost of the conduct of testing. Areas of particular application include scenario development; analysis of tactics and doctrine for systems; timing of test events; the development of objectives, essential elements of analysis, and measures of effectiveness; the identification of variables for control and measurement, training test participants in preferred tactics and doctrine, and the development of data collection, instrumentation and data analysis plans. For example: using M&S, the test designer can examine system sensitivities to changes in variables to determine the critical variables and the appropriate ranges of values to be tested. The test designer can also predict prior to testing, the effects of various assumptions and constraints and can evaluate candidate measures of effectiveness to help in formulation of the test design plan.

Table 1. Overview of M&S Application in Support of T&E.

1. Support pretest planning.
2. Identify key test parameters earlier.
3. Bound, in a gross manner, the problem and propose solutions based on the intended environment, force structure, threat, tactics, strategy, and doctrine.
4. Identify oversights and flawed logic.
5. Determine sensitivity of a system to various input parameters.
6. Allow non-destructive testing of high cost items.
7. Provide better understanding when full-scale testing is not possible.
8. Augment, extend, and enhance test results, as appropriate.
9. Provide multiple "environments" for examining test objectives.
10. Provide advantages of test compression, control expenditures, enable replication, and reduction of variables under study.
11. Assess impact of known parameters of unavailable threat systems.
12. Accomplish human factors supportability or soldier-machine interface analyses in part-task or limited fidelity "mock-ups."
13. Provide estimates of potential test outcomes.
14. Extrapolate, with caution, test results into other scenarios and levels of force aggregation.
15. Address issues which cannot be physically tested.
16. Address "what if" questions during post-test analyses.
17. Develop and refine test scenarios and data matrices to obtain maximum data from limited test resources.
18. Develop new tactics for the employment of new weapon systems under test.
19. Provide overall system, scenario, or environment representation.
20. Represent the input, process, and output of non-available systems, subsystems, or components (friendly or threat).
21. Represent the whole integrated system when all components are not available.
22. Allow an assessment of test events that would otherwise be exposed to threat intelligence exploitation.
23. Act as a system driver or stimulator in order to stress a system beyond available test scenarios.
24. Determine adequacy of the planned operational, maintenance, and supportability concepts.
25. Estimate mature system mission reliability, availability, and logistics support frequency.

(2) Test capabilities and limitations drive evaluation planning. Likewise, M&S capabilities and limitations, balanced against test capabilities and limitations, will drive the planning of the overall simulations, test, and evaluation effort. Human resources, financial resources, safety, environmental concerns, real estate, and time typically limited tests. M&S limitations typically result from inadequacy in model complexity or computer capacity to provide the desired resolution and fidelity, from incomplete knowledge or human bias about the phenomena being modeled, or lack of a sufficient database to support the M&S.

(3) Computer simulations may be used to test the planning for a test exercise. By setting up and running the planned test exercise in a simulation, the timing of events and scenario may be tested and validated. The interaction of the various forces represented during test; the measures of effectiveness, the essential elements of analysis and, in turn, the test objectives may identify critical events. Further, the simulation may be used to verify the statistical test design, the instrumentation plan, the data collection plan, and the data analysis plan. Essentially, the purpose of the simulation in pretest planning is to preview the test exercise to make test planning more efficient. Pretest planning attempts to optimize test conduct by avoiding potential trouble spots and increasing the potential for efficient data collection.

(4) As an example of a simulation used in test planning, consider a model that portrays aircraft versus air defenses. The model can be used to replicate typical scenarios and provide data on the number of engagements, the air defense systems involved, the aircraft target, the length and quality of the engagement and a rough approximation of the success of the mission (i.e., did the aircraft make it to the target?). With such information available, a data collection plan can be developed to specify in more detail when and where data should be collected, from which systems, and in what quantity. The results of this analysis can be extremely useful in planning for long lead-time items such as data collection devices and data processing systems. As tactics are developed and typical flight paths are generated for the scenario, an analysis can be performed on the flight paths over the terrain in question. A determination can be made whether or not the existing instrumentation can track the numbers of aircraft involved in their maneuvering envelopes. Trade-offs can be made between the amount of equipment to be purchased and the types of profiles that can be tracked for this particular test. Use of such a model can also highlight numerous choices available to the threat air defense system in terms of opportunities for engagement, and practical applications of doctrine to the specific situations.

b. Support Test Execution.

(1) Simulations can be useful in test execution and dynamic planning. With funds and other restrictions limiting the number of times a test event may be repeated, and with test events sometimes requiring several days for completion, it is mandatory that the test director exercise close control over conduct of all test elements so as to ensure that planned data are being gathered and to ensure adequate safety. The test director and M&S Customer must mutually

agree to modifications to the previously agreed test plan and scenario. This calls for a quick-look analysis capability and a dynamic planning capability. Simulations may contribute to this capability (e.g., using the same simulation(s) as used in the pretest planning, the tester could input data gathered during the first day of the exercise to determine the adequacy of the data to fulfill the test objectives). Using these data, the entire test could be simulated to isolate and to modify the test plans. Portions of the test could be deleted to save resources. M&S can provide repeatable test scenarios and results.

(2) Simulations may be used to support test control and to assure safety, e.g., during missile test firings, aerodynamic simulations of the proposed test were run on a computer during actual firings so that real time missile position data could be continuously compared to the simulated missile position data. For example, if variations occurred beyond acceptable limits and if the range safety officer relinquished manual control, the computer could issue a command to destruct the missile.

(3) Simulations can augment test execution in order to reduce costs. For example, in air defense systems, missile fly-out simulations may be used in conjunction with system testing to reduce the expenditure of live missiles while providing information on overall system performance. Simulations can also be used to augment test execution by providing a means to simulate stress (or workload) to the system under test. For example, it may be prohibitive to set up a network of message traffic to adequately stress a communication system, but a simulation may be used to provide sufficient (simulated) message traffic to the system under test at a reasonable cost.

(4) Simulations can be used to augment tests by simulating non-testable events and scenarios. Although testing should be accomplished in as realistic an environment as possible, pragmatically, some environments are impossible to simulate for safety or other reasons. Some of these include the environment of a nuclear battlefield to include the effects of nuclear bursts on both friendly and enemy elements. Others include live firings of opposing forces and adequate representation of other forces to obtain compatibility and interoperability data. Instrumentation, data collection, and data reduction of large combined arms forces (e.g., brigade, division, and larger-sized forces) become extremely difficult to control and costly to execute.

(5) Usually, insufficient units are available to simulate the organizational relationships and interaction of the equipment with its operational environment, particularly during early OT conducted using prototype or pre-production type equipment. Simulations are not constrained by these limitations. Data obtained from a limited test can be used in more complex M&S to depict scenarios involving the interaction of friendly forces against several of threat systems.

(6) Simulations can represent design characteristics of equipment and can be used to augment the results obtained using prototype equipment that is "mocked-up" to represent the final item. The simulation may be used to represent production level equipment in those areas where the prototype cannot meet production level performance.

(7) It is often necessary to use surrogate systems in testing, i.e., an on-hand available system is used to represent the required system. The surrogate system may have greater or less capabilities than the desired system. Simulations are capable of representing the actual characteristics of systems and, therefore, can be used as a means of modifying raw data collected during the test to estimate the required system characteristics. As an example, a substitute system for an anti-aircraft artillery gun has a tracking rate of 30 degrees per second. The required system has a tracking rate of 45 degrees per second. A computer simulation could augment the collected test data by estimating the number of rounds which would have been fired against each target or whether targets that were missed because of the slower tracking rate could have been engaged by the required system.

c. Support Analysis.

(1) Modeling and simulation may be used in post-test analysis to extend and generalize results and to extrapolate to other conditions (See Appendix C, paragraph 3.b). The cost and difficulty of controlling large test exercises, not to mention the difficulty in instrumenting them and collecting and reducing the data, to some degree limits the size of OT&E. This makes the process of determining the operational suitability of equipment to include compatibility, interoperability, organization, etc., a difficult one. To a large degree, using data collected during the test and playing it in a simulation may obtain the interactions, interrelationships, and compatibility of large forces.

(2) Simulations can be used to extend test results, save considerable test resources, and reduce test cost. This is accomplished by minimizing the need to replicate tests for the improvement of statistical sample, determining overlooked or directly unmeasured parameters.

(3) During analyses the test results can be compared to the results predicted by the simulations used early in the planning process. Thus, the simulation may be validated by the actual live test exercise results, and the test exercise may gain credibility from the comparison with the simulation.

(4) M&S have provided valuable post test failure analysis support. This has been especially useful in the analysis of wheeled vehicle roll-over events.

9. System Evaluation Planning.

a. Force-on-force models support the evaluation of a system's contributions to total force effectiveness. Early in the Concept Exploration Phase, competing system employment concepts can be examined in distributed simulation using a model of the proposed system, operated with models of other systems and forces, representing the battlefield where the system will perform. M&S can be applied to establishing key test requirements by using it for analysis of the system using common measures (e.g., MOE and MOP).

Example: A new counter-battery radar will be evaluated in a force-on-force model. The model, typically JANUS or Modular Semi-Automated Forces (ModSAF), includes the command, control, and communications links to both the counter-fire weapons and to other friendly elements that are supported by or protected by the new system. The model represents the threat force, including countermeasures that can jam the radar or its communications, and artillery capabilities used against the friendly force. Threat elements can detect and attack the radar and its command and control. The developmental radar's contributions can be evaluated in terms of the survivability of the total force.

b. Estimating System Performance Envelope. System design and interoperability can be examined early in its expected operating environment. High-fidelity engineering models can be used to design test events of the system's objective performance requirements, estimated flight paths, and scale down test scenarios.

Example: The Patriot Advanced Capabilities Simulation provides a high-fidelity digital simulation of the surveillance function, missile dynamics, and lethality function for pre-flight predictions and post-flight reconstruction of flight tests. The Mission Planning and Real-Time Test Analysis (MPARTTA) System uses missile fly-out models to plan optimum optics, radar, and telemetry placement, rehearsal, and flight safety evaluation.

10. Test Scenario Planning. M&S can be used to design test scenarios and plan the sequence of trials. Using the system model or distributed product description, the tester and/or evaluator can simulate the mission process to time events, examine control variables, and select the best places to place instrumentation or collect data.

Example: A communications engineer or spectrum manager can use the Virtual Electromagnetic C4I Analysis Tool (VECAT) for planning specific communications links or performing area site analyses to show where bottlenecks might occur and help identify which nodes to instrument. VECAT could also be used to plan a test of a sensor system immersed in a synthetic battlefield environment, which would be impractical to duplicate in a field-test situation.

11. Drive Test Instrumentation. Physics-based models of expected system performance can be used to control the test instrumentation, and validate the data in real time, during the execution of live tests of complex systems in complex environments.

Example: Models of the trajectory of a projectile or rocket, deploying multiple submunitions, drive tracking radar, which, in turn, controls the video, focal plane staring arrays, film cameras, and ranging radar. Integrated and controlled by high-speed networks and computers, the Smart Munitions Test Suite captures flight and impact data on up to 40 submunitions simultaneously from carrier vehicle disbursement to impact.

12. Create System Loading. High performance simulators and stimulators generate and render synthetic environments and stimuli to induce, in the system under test, the same response that the actual environment or stimulus would in a battlefield situation.

Example: Throughout the life cycle, infrared-seeking tactical missiles are immersed in synthetic flight environments in the Electro-Optical Sensor Flight Evaluation Laboratory to exercise and evaluate the performance of the entire missile seeker/guidance and control system and sub-systems. The hardware-in-the-loop facility presents dynamic IR scenes that include target signature and motion, terrain features, natural and man-made obscuration, and foliage, to the seeker. At the same time, the missile airframe "flies" in a 6 degree-of-freedom fixture that provides climatic conditioning, dynamically loads its control surfaces to simulate aerodynamic forces, while instrumentation feeds back flight control movements to the fixture and the dynamic IR scene projector.

13. Test Scenario Driver. Use of M&S during OT, especially for communications, command, control and intelligence (C3I) systems, can provide affordable operational realism while avoiding large troop deployments.

Example: Simulation, Testing, Operations Rehearsal Model (STORM) is a simulation and stimulation tool for the operational testing of Force XXI Battle Command Brigade and Below (FBCB2) system. STORM operation begins with the JANUS force-on-force simulation producing DIS Protocol Data Units, giving information on all the entities in the simulation. The data from JANUS is converted into Variable Message Format and merged with Situational Awareness position reports for completely simulated units. A GPS model adds realistic GPS error, and communications effects models add the effects of RF path loss degradation and terrain masking, when appropriate, before the message is sent out. The message is transmitted onto the Tactical Internet by a stimulator that is capable of interacting with the same tactical radios as the live systems, so that the live units, using the FBCB2, receive the messages from STORM just as received from other, live units. Driven by JANUS, STORM creates a realistic environment for brigade and below operations, simulates phenomena, and distributes input messages to live players for scenario generation, test rehearsal, simulation, stimulation, data collection, reduction, visualization and analysis of C3I systems.

14. Assess Vulnerability and Lethality. The assessment of system vulnerability to battlefield threats has traditionally required a significant degree of modeling, with empirical validation of simulation results to support the assessment.

> Example: Vehicle vulnerability modeling begins with a 3-dimensional geometric model of a vehicle system, defining the spatial relationship of the armor envelope and system components and subsystems. Ballistic testing provides vulnerability test data to characterize the threat/armor interaction performance to support development of the ballistic performance and behind armor debris algorithms used in the vehicle vulnerability models. Penetrator and behind armor debris effects are projected onto components and subsystems, to investigate how damage to those items contributes to system loss of combat function. The system level live fire test demonstrates the synergistic effects of complex damage mechanisms. Test results can lead to design improvements and improved models, and provide input to designers of future systems.

> Example: Advanced Distributed Electronic Warfare Simulation (ADEWS) overcomes restrictions on the use of open-air jamming to evaluate the vulnerability of communications systems to jamming by injecting controlled jamming signals directly into the system under test. Using ADEWS, the tester/evaluator can avoid FCC and FAA restrictions on open-air jamming, eliminate operational security concerns of broadcasting classified jamming signals, reduce costs by not deploying actual threat assets, record and replay jamming signals, and conduct repeatable tests in electronic warfare environments across large-scale deployments.

Weapon system lethality M&S provide the capability to investigate complex interactions, through many iterations, for a small fraction of the cost of live testing.

> Example: A computer-based virtual test range simulation was developed for evaluating the lethality of high-explosive anti-tank rounds, with proximity fuzing, in tank versus helicopter engagements. Flight paths of the helicopter, trajectories of the prototype round, fuze performance, and kill distance were modeled based on actual flights and previous firings. Simulated helicopter engagements were conducted with an actual manned tank; with simulated projectile miss distance recorded for each engagement. Eighty such "virtual" firings were conducted. The simulations were verified by actual engagement using a live round against a drone aircraft. Significant cost avoidance resulted from not having to fire a complete test program of live rounds against live targets.

15. Examine Alternative Environments. Generally, it is impractical to exercise a weapon system in every environment it is likely to encounter on the battlefield. High-resolution computer modeling and synthesis of environmental characteristics, rendered in a manner compatible with the system's sensitivities can provide precise, versatile, and repeatable variations of the operational environment, quickly and at low testing cost.

Example: Atmospheric Effects Modeling provides the tools to synthesize atmospheric effects that can be used to predict the movement of chemical/biological threats and obscurant clouds. Synthetic atmospheric effects can be superimposed on electro-optical scenes for hardware-in-the-loop stimulation and human-in-the-loop simulation, or to influence the signal transmission/receiving performance in computer-based simulations of communication networks.

16. Extend Test Results. System effectiveness models often provide the critical link between test data and the evaluation of a system's battlefield contribution.

Example: Accuracy and dispersion test data, in conjunction with munitions effectiveness models, are used by evaluators to predict probability of hit and probability of kill for a weapon system under specific conditions. Outputs are used with combat models such as the Combined Arms and Support Task Force Evaluation Model (CASTFOREM) or Modular Semi-automated Forces (ModSAF) model to make predictions.

17. Examine Effects of Test Limitations. During post-test analysis, differences between M&S predictions and actual test data are reconciled in support of the system evaluation. Differences may indicate a need to refine the model, or may indicate that test conditions were outside of expected bounds. Once confidence is established, the M&S can be used to interpolate (or in some cases, even extrapolate) (See Appendix C, paragraph 3.b) to other conditions under which the system could not be tested.

18. AoA Model and Test Linkage. For acquisition systems that require an Analysis of Alternatives (AoA), the AOA model must address military utility in MOE/MOP that can be substantiated by T&E. Early in a program, the ability of the system to meet requirements may simply have been assumed in the AoA model. However, for M&S to be useful in substantiating, through T&E, that thresholds of effectiveness are being met, the models must be based on accepted physical principles and/or empirical data. When the item under test is a computer-based model of a system or subsystem, with a degree of functional realism that is comparable to that of a physical prototype, the item under test may be referred to as a "virtual prototype." Testing of a virtual prototype may be done to determine the validity of the model for other uses, or to predict the performance of the modeled system when acted upon by modeled stimuli. In the first case, the model is scrutinized and exercised to ensure that its performance characteristics meet acceptability criteria, toward accreditation for the intended use. In the latter case, not only must the virtual prototype have been accredited for the purpose of the test, the virtual prototype with the modeled stimuli interaction must be accredited by whoever intends to use the outcome of the simulation.

Example: Transportability simulation testing is done to predict the performance of weapons systems undergoing the MIL-STD-810 transportability tests (rail impact, tunnel clearance, sling lift, fit into aircraft, tie-down). System virtual prototypes from the developer, that model the geometry and dynamic responses of vehicle chassis and suspension, can be interacted with kinematics and dynamic models of the transportability test procedures. Doing these tests in simulation early, and at substantially less cost than a live test, allows for any necessary redesign when it is most cost-effective, before the hardware prototype is built. The simulations are backed by substantial live proving ground validation. When used for design decisions, the design engineers accredit the M&S. When used to certify transportability, they are accredited by the Military Traffic Management Command.

19. Test Rehearsal and Training. M&S resources developed to support testing of weapons systems can also be useful for test rehearsal and for training soldiers in the use of those weapons systems. Conversely, training simulators may have applicability to testing. Early coordination between the PM, ATEC, and TRADOC members of the M&S WIPT can result in significant cost avoidance by combining training and testing M&S requirements. In such a situation, M&S accreditation, based upon unique acceptability criteria, may be the only development expense. Testers should be mindful of opportunities to influence future TRADOC M&S products that can satisfy test stimulation acceptability criteria.

Example: An Advanced Infrared Simulator (AIRS), based on target acquisition system test instrumentation, provides realistic FLIR imagery for training on a tactical weapon system. A digital scene injector effectively bypasses the optics of the FLIR weapon system, injecting "real" second generation FLIR imagery into the weapon system at a real-time rate to create the IR scene. Live interaction between the soldier and the weapon system includes switch operation training; target detection, recognition and identification; virtual missile firings and precision gunnery skill training. AIRS can apply to any system with second generation FLIR technology.

Example: To enhance intelligence training at the National Training Center, Combat Synthetic Test and Training Assessment Range (CSTTAR) merged a JANUS constructive wargame simulation around real time position and event data, using Distributed Interactive Simulation (DIS) Protocol Data Units. The merged data units were injected into J-STARS and UAV simulators, which produced realistic data streams and scenes to the intelligence units using the All Source Analysis System. The result was to effectively increase the occupied training area ten-fold, along with information about engagements in the surrounding battlefield.

20. M&S Development. T&E products have application to M&S from the outset of a system's life cycle process. Testers may be called upon to provide performance data from previous or surrogate system (or component) testing so as to feed the creation of a system model. In these cases, it is critical that the tester work closely with the modeler to ensure that the right data is taken, and that the data is understood and applied appropriately in the system model.

> Example: Performance data taken during the stockpile reliability testing of HELLFIRE missiles are used by the missile developer to develop and refine the guidance and control characteristics of the system model. Close interaction between the developmental tester and the missile developer resulted in a more accurate representation of actual missile flight control in the system model. Thus, the model will serve as the basis for future enhancements in anti-tank guided missile control.

> Example: Testing for the Halon Alternatives Program provides a source of data on the propagation and suppression of engine compartment fires in armored vehicles. Through a model-test-model process, testing will refine models of fire initiation, propagation, and suppression. Once credibility is established, the models will be used to understand the fire suppression phenomena, extrapolate into non-testable scenarios, drive simulators, design test scenarios, and as input to armored vehicle design.

21. M&S Weapon System Examples. Appendix B provides examples of M&S used in support of specific weapon systems' T&E. While not exhaustive, these examples represent instances where M&S have been used effectively in T&E. Appendix C provides examples of other T&E-related use of M&S. Additional examples can be found at DoD and Army M&S Resource Repositories.

Section IV
M&S Credibility for T&E

22. M&S Verification and Validation. V&V and T&E are fundamentally related. Verification, which ensures that the product works as intended using sound system engineering techniques, is analogous to developmental testing. Validation, which ensures that the M&S is realistic from the perspective of its intended use, is analogous to operational testing. V&V and T&E activities provide significant support to one another. As such, both benefit in cost, schedule and risk reduction from their integration. T&E planning and execution should occur in parallel with the V&V effort and leverage from the V&V Plan to ensure coordination between these two processes. A comprehensive M&S strategy will validate model input and output data, comparing data with corresponding known real world or best-estimate values to ensure data are appropriate and reasonable for their intended use.

23. Credibility of M&S.

a. As the use has increased, M&S have grown in size and complexity. Many M&S that support the acquisition process are too complicated to be sufficiently understandable by decision-makers, testers, and analysts. Such a situation has led to concerns related to M&S application. It is important to ensure that M&S results used to support major T&E are credible. M&S VV&A must be accomplished to ensure a high level of confidence in the results provided such M&S. The M&S user must determine if the M&S, or its algorithms, are suited for the intended use. Moreover, the M&S user must determine if the M&S was designed to operate in the intended framework of the new application.

b. An essential attribute of any useful M&S is that it has earned a high degree of credibility (i.e., its construction, execution, and the interpretation of its output results are considered to be good and true when taken in the proper context by a community of peers).

c. System and subsystem models at the engineering level, particularly those which model functions that do not represent combat environments, seem to enjoy a fairly high level of credibility among analysts and decision-makers, e.g., it is virtually impossible to imagine a modern aircraft development program that would not make extensive use of wind tunnels and flight dynamics simulations. It has been shown that these simulations frequently permit a reduction in the number of aircraft flight hours required during the development process. This high level of simulation credibility can be attributed to the degree of development of aerodynamic sciences (at least empirically) and the use of instrumented aircraft flight test data collected to continually improve the fidelity of such simulations.

d. Complex combat M&S, which estimate operational performance, encounters more skepticism among decision-makers. Such a situation may be due to the complex combat M&S simplifying assumptions, the fact that the fundamental theoretical mathematical basis for aggregation and disaggregating are less well understood, or that the M&S is based upon physical principles so as to provide a basis for further extrapolations (See Appendix C, paragraph 3.b). The difficulty in representing the impact of human performance factors in combat (i.e., stress, fatigue, and shock) adds to the skepticism. It could be argued that nothing short of actual combat, with instrumentation to collect data, could fully resolve all suspect M&S elements. The use of multiple M&S with different theoretical approaches and assumptions may provide a hedge against the uncertainty of our fundamental knowledge of combat processes and of our ability to implement these processes into a M&S. These different approaches and assumptions must be made clear, however, or the different M&S are likely to generate more confusion than insight. Nevertheless, a M&S' concentration on component and sub-system performance is considered value added, even though it may lack the capability to demonstrate a sub-systems effect(s) on the system (i.e., degraded state of functionality).

24. Verification, Validation, and Accreditation (VV&A) of M&S

a. The Department of Defense (DoD) has long recognized the value of M&S that can be found in every aspect of DoD. M&S support major DoD acquisition decisions as well as the warfighter. In 1994, DoD Directive 5000.59, Modeling and Simulation Master Plan, mandated VV&A policies, procedures, and guidelines are established. Further, the Army provided general guidance in Army Regulation 5-11, Management of Army Model and Simulations, detailed guidance in DA Pamphlet 5-11, Management, Verification, Validation, and Accreditation of Army Model and Simulation. They state that VV&A will be conducted concurrently as part of the M&S life cycle management process for each individual model and simulation.

b. The VV&A process ensures that each M&S and its data are being used appropriately for each specific purpose (e.g., developing a tactical mission plan, training a warfighter or supporting equipment development/ redesign for the warfighter). Figure 2 illustrates the support relationship of VV&A to M&S. Appendix D depicts the integration of VV&A into the M&S life cycle management process.

c. VV&A is a two-phased process with several steps.

(1) The first phase consists of V&V functions.

(a) Verification addresses the question – Does the M&S work as intended? Specifically, verification is the process of determining that an M&S accurately represents the developer's conceptual description and specifications. Also, verification assesses the extent that the M&S has been developed using sound and standard software engineering techniques. Verification is applied at each stage of the M&S life cycle management process to ensure that the inputs and outputs are implemented accurately and properly as well as support the purpose of the M&S. Therefore, verification double-checks if the M&S code and logic are correct and perform the intended functions accurately. In short, verification builds confidence in the structural integrity of the M&S.

(b) Validation addresses the question - Is the model realistic? Specifically, validation is the process of determining the degree to which an M&S accurately represent the real world from the perspective of its intended use. Thus, validation examines the concept and output thoroughly. Data obtained from the real world or a credible source, which has been proven by a recognized expert is used to compare the M&S behavior and results. In short, validation is the cornerstone by which the credibility in M&S is built.

(c) Verification and validation are complementary processes and, together, function similar to the quality control used in the manufacturing process. Ultimately, the combined purpose of V&V is to support the accreditation process and ensure the M&S provides credible results and satisfies the users operational needs relative to the intended use. The M&S developer is responsible for V&V.

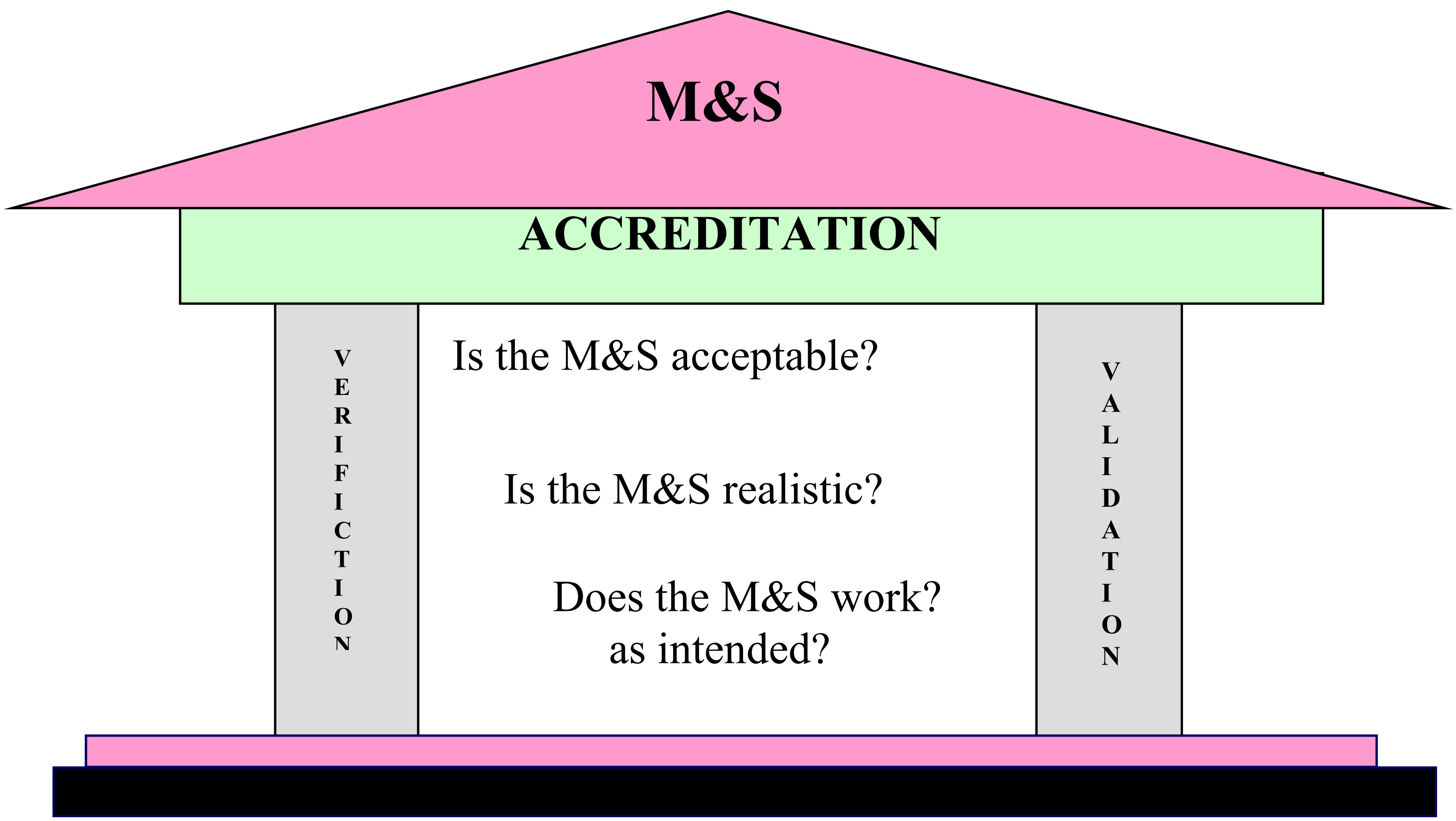


Figure 2. Relationship of VV&A to M&S.

(2) The second phase is the accreditation function. Accreditation addresses the question - Is the M&S acceptable or suitable for a specific use? Accreditation is the official determination that an M&S is acceptable for a specific purpose. Thus, accreditation is a set of formal procedures so as to gain confidence in an M&S.

(a) Accreditation is a decision by the user to use a M&S, and its results, for a particular application. However, accreditation is based on properly performed and documented V&V information, which is used to compare against an exit criteria, formally called acceptability criteria. Accreditation is developed and documented at the beginning of the M&S life cycle management process. The acceptability criteria are unique to each M&S intended use and provide essential insights to possible solutions. Therefore, the acceptability criteria are standards that the M&S must meet in order to be accredited (i.e., used for a specific purpose).

(b) A sample listing of questions supporting an M&S accreditation to be addressed are illustrated in Table 2.

(c) For details on the VV&A activities within the life cycle management process refer to the Department of the Army Pamphlet 5-11 at http://www.amso.army.mil.

25. Limitations of M&S. Just as the capabilities and limitations of live testing drive evaluation planning, the capabilities and limitations of M&S, balanced against the capabilities and limitations of live testing, will likewise drive the planning of the overall simulation, test and evaluation program. While tests are typically limited by human and financial resources, safety, environmental concerns, real estate, and time, M&S limitations typically result from inadequacy in model complexity or computer capacity to provide the desired resolution and fidelity, or from incomplete knowledge or human bias of the phenomena to be modeled.

Example. Battlefield simulations may allow engagements at longer ranges than occur in the real world because contours that provide cover and concealment in the real world are beneath the level of detail (resolution) contained in the terrain model. Similarly, vegetation that exists on the actual battlefield may not be represented with fidelity in the model. Such limitations should be identified during the V&V effort before the M&S is performed. V&V determines how well the M&S works for the application(s) intended. Any pertinent limitations should be fully documented in the accreditation.

By law (10 US Code 2399), the initial operational test and evaluation of a major defense program's system effectiveness and suitability must not be based exclusively on computer modeling, simulation or analysis of system requirements and design specifications.

Table 2. Credibility Issues to Address in Using M&S to Support T&E.

M&S credibility is essentially derived from the overall quality of the various inputs and processes used in development. When M&S are used to support T&E, the following questions related to credibility should be considered.

A. Verification, Validation, and Accreditation (VV&A) Related Issues.

1. Has the M&S gone through a similar approved process to establish its credibility?

2. Were M&S results compared with combat, field test, & other M&S? If so, what were results?

3. What have the M&S results been validated against?

4. What are the availability, date, and source of data? Are data available to support system requirements? If not, what assumptions will be made? How will critical variables be represented? Is there imbedded data in the M&S? If so, are those variables documented and is the data defined? Who has reviewed and certified the use of the data for the study?

5. How robust are the results on operational capability and supportability?

6. Who built the M&S?

7. Who certified the M&S data inputs?

8. Who certified the tactics/scenarios or changes to existing scenarios?

9. Who did the M&S verification and validation?

10. What implicit and explicit assumptions were made? What are the M&S limitation(s)?

11. Is there sufficient M&S documentation, its assumptions, data requirements and methodology?

12. What sensitivity analyses have been performed?

13. How far has the M&S been pushed to extremes and how has it performed? Has the M&S domain been established?

14. What field test results have been fed back into the M&S for validation?

15. Is there a documented audit trail of data, methodology and code changes, and scenario changes? Will it provide traceability of critical decisions?

16. Who maintains the M&S?

17. What is the source of threat data? Is it consistent with data used in other analyses? What is the source of threat (RED) tactics used in the scenario?

18. What variables of the operational environment are not represented in the M&S?

B. Evaluation/Study Concept Related Issues.

1. Why was M&S used in lieu of testing? What specific issues are to be addressed by the M&S?

2. Was M&S discussed in the TEMP?

3. Did the simulation accurately reflect the system requirement or available DT test data?

4. What is the linkage, if any, between DT, OT, and M&S?

5. Why was this particular M&S chosen? What was it designed to do? What are its strengths/weaknesses? Where has it been used before?

6. Is there adequate funding to support the M&S? By whom? Is the M&S cost-effective?

7. What elements of M&S should be confirmed by operational testing?

8. Were excursions conducted on critical variables and system parameters? If so, why and what were they?

9. What impact (if any) did the M&S excursions have on the evaluation?

10. What is the degree of independence of modelers with respect to the program office, materiel developer, and system contractor? If the M&S developer is associated with the program office, who conducted the independent assessment of the M&S applicability?

11. Has this M&S been used by the developer of the weapon system under test or being acquired? What were the results?

12. Who is expected to use or operate the M&S?

13. Can the M&S be designed, built and/or modified faster and/or cheaper than the system it represents?

14. If multiple M&S are used, what are the linkages? What are the data structures?

Section V
M&S Planning

26. Considerations for M&S Use in T&E. Planning an integrated simulation, test, and evaluation program begins with the traditional T&E planning process (reference ATEC Regulation/Pamphlet 73-1), in association with a system's Integrating Integrated Process Team (IIPT), the T&E Working IPT (T&E WIPT), and the ATEC System Team (AST). An M&S WIPT may also be formed, either as another working IPT to the IIPT or to the T&E WIPT.

a. Evaluation Planning. A system's requirements are identified in the Mission Need Statement (MNS), Operational Requirements Document (ORD), and the concept of operations as stated in the Operational Mode Summary/Mission Profiles (OMS/MP). A system's requirements are used to the develop an evaluation dendritic, which uses the system's critical operational issues and criteria (COIC) and Additional Issues (AI), to develop measures of effectiveness (MOE) and measures of performance (MOP). Based upon the COIC, the independent evaluator develops Additional Issues to formulate a comprehensive evaluation concept to determine a system's operational effectiveness, suitability, and survivability. An AI can be either operational or technical in nature. An operational AI could be based upon a particular ORD requirement. A Technical AI could be based upon a system's Critical Technical Parameter documented in the approved TEMP. MOE and MOP address a system's military utility and can be linked to the system's AoA.

b. Data Source Identification.

(1) Based upon the evaluation concept, data sources are then identified to provide the necessary data to develop the MOE and MOP for performance, survivability, vulnerability, lethality, reliability, maintainability, transportability, MANPRINT, logistics supportability, and safety evaluation issues.

(2) Sources of data to address each of the evaluation areas can include studies, prior analyses or reports, DT events, OT events, and Combined DT/OT events as well as M&S events. The resultant product is called a Data Source Matrix (DSM) that is appended to the System Evaluation Plan (SEP). Successful data source planning depends upon thorough awareness of testing, modeling, simulation, and evaluation tools available.

c. Evaluation Strategy. The type of system under evaluation will influence the evaluation strategy, to include the DSM. In general, complex systems (to include those that require complex interaction with their operating environment) require investigation of many parameters and, thus, favor the application of M&S tools. For less complex systems and data requirements, live filed testing may be used. There is a broad continuum of modeling, simulation, and test tool applications available for each type of data requirement.

d. M&S Selection Principles for DSM. The first consideration when identifying M&S as a data source (e.g., DSM) is to review what type of data is needed under what conditions. Then, a need exists to determine criteria for M&S acceptability that addresses accuracy, precision, and sensitivity to inputs and assumptions. M&S selection as a data source is based on matching the functional requirements to available M&S. A complete set of functional requirements should be sufficient to choose the M&S that best matches the requirements. M&S selection will include consideration of the following:

(1) Output relates directly to required MOE and MOP.

(2) Inputs are known, or readily available from testing or other sources.

(3) Required assumptions are known, valid, credible, and defensible.

(4) M&S is compatible with available computer platforms, system stimulators, hardware/human-in-the-loop simulators, and other models with which it will interact.

(5) M&S can be modified at a cost, if necessary, to meet acceptability criteria.

(6) M&S used, is consistent with those used, or is acceptable for reuse, elsewhere in acquisition process (concept exploration, design, manufacture, training, and maintenance).

(7) M&S presents output data in a way that facilitates the evaluation process.

(8) M&S provides relevant, realistic, controllable, repeatable, affordable synthetic environment or stimulus.

(9) Use of the M&S reduces the time or cost of a live test event.

(10) Government has data rights to model.

(11) Degree to which the M&S has undergone V&V, or is sufficiently documented to allow affordable V&V and appropriate accreditation with minimal live testing. (See note, below.)

The selection of M&S tools and events should be coupled with the analogous considerations for selection of live test events so as to ensure that the most cost-effective approach to execute the evaluation strategy approach is developed. M&S and tests are mutually supportive rather than isolated or duplicative.

NOTE: Once identified for use, and before actual application, M&S must undergo VV&A. That is, verified for logical stepwise process and use of sound software engineering techniques; validated for output relative to input that is comparable to real world observations, from the perspective of its intended use; and officially accredited as a source of realistic conclusions for a specific application.

e. Formal Documentation of M&S Use in T&E. T&E planning is documented in the System Evaluation Plan (SEP), applicable Event Design Plans (EDPs) and Detailed Test Plans (DTPs), and the Threat Test Support Plan (TTSP). The hardware and M&S resources identified in these plans are reflected in multiple sections of the Test and Evaluation Master Plan (TEMP). All M&S planning, including that which supports T&E, is also documented in the system's Simulation Support Plan (SSP). Any T&E support to M&S (i.e., validation) should also be documented in the SSP and the TEMP. The M&S portion of the TEMP should closely coincide with the T&E portion of the SSP.

27. M&S and T&E Linkage Concept.

a. Decisions concerning the use of M&S should be made as early in the acquisition cycle as possible to support the timely development of any new M&S or any required upgrades to existing M&S. This requires early coordination (as soon as possible after Milestone 0) among the user, developer, testers and evaluators. M&S strategy use should begin as part of the Integrated Concept Team (ICT) process initiated by TRADOC's Battle Labs or Directorate of Combat Development. Likewise, Advanced Technology Demonstrations (ATDs) and Advanced Concept Technology Demonstrations (ACTDs) should develop M&S strategy use that can be passed along to the system's PM as the materiel development process matures. Ideally, the user, developer, testers, and evaluator will agree (not later than Milestone I) on the M&S needed for a system. A plan should be developed at this time to transition the generic modeling capability specified at Milestone I to a mature, fully defined M&S requirement by Milestone II (for execution between Milestones II and III). In addition, data requirements and acquisition of input data for M&S are essential and are often long lead-time items.

b. To ensure the validity of Theater/Campaign and Mission/Battle analyses, M&S must correctly represent threat force system capabilities, threat force combat, threat combat support, and threat combat service support. Treatment of the threat is key to M&S validation and accreditation. Threat is generally addressed through equal representation in the model input data, decision rules, and scenario specifications (i.e., force structure and composition, weapons/munitions). Those conducting analyses must know the strength, weaknesses, and limitations of any model selected with respect to representation of the threat. Threat data provided by supporting intelligence organizations must be accurate, current, and derived from validated intelligence products and databases. IAW AR 381-11, deviations from validated scenarios or threat data, must be documented and forwarded through the Army Test and Evaluation Command (ATEC), and the Department of the Army Deputy Chief of Staff for Operations and Plans (DA DCSOPS) to the Department of the Army Deputy Chief of Staff for Intelligence (DA DCSINT) for approval. Each of these organizations should be invited to participate in the development of the system's analysis plan(s). The analysis results must indicate any deviations and associated implications.

c. Current acquisition policy (DOD 5000 series) states that the AoA and T&E are aids to decision-making. The Analysis of Alternatives (AoA) aids decision makers in judging whether any of the proposed alternatives offers a cost effective approach to meeting the operational requirement. T&E supports decision makers by verifying that systems have attained their technical performance specifications and objectives and that they are operationally effective, suitable, and survivable for their intended use. Ensuring that the M&S and data used in a system's AoA are continually validated throughout the system's acquisition process is essential to providing the best possible information is available to decision makers.

Section VI
M&S Sources

28. Tools Enabling Development of Credible M&S.

a. The Army Model and Simulation Office (AMSO) (www.amso.army.mil) Standards Nomination and Approval Process (SNAP) is a web-based tool used to track, discuss, and vote on standards nominations from the M&S Community. Any individual may identify a new M&S standard requirement by submitting a Standards Requirements Document (SRD) for consideration. The term standard is applied in the broadest context to include procedures, practices, processes, techniques, data, and algorithms. Standards for M&S cover a variety of topics and the type and source of relevant standards will vary with each standards category. Several types of standards for data apply: meta-data, data structures, raw data, and data storage and transmission. Standards also exist for the process associated with the development and use of M&S. Examples are standards for building simulation object models, federation object models, and conducting Verification, Validation, and Accreditation (VV&A). Standards are developed within the Army M&S community and are also adopted from other disciplines and organizations. The Army M&S standards development process builds technical M&S algorithms, heuristics, procedures, and other appropriate M&S standard methods, to support commonality, reuse, credibility, and interoperability. Presently, 19 standards categories exist which support the objectives outlined in the Army M&S Master Plan.

b. The Army Standards Repository (ASTARS) is a user-friendly web-based tool that houses all approved Army M&S standards. ASTARS allows searches with relative ease for a standard within a given M&S standards' category. Each approved standard in ASTARS, contains a brief description of the standard, to include its utility and limitations, as well as a point of contact. To the extent possible, download information or links to other websites where the standard can be accessed will also be provided. ASTARS allows the user to search by standards category or conduct a general search of all standards, tools, and documents in the repository by title, description, or keywords.

c. The Army M&S Resource Repository (MSRR) is part of the DoD-wide Model and Simulation Resource Repository (MSRR). MSRR promotes interoperability, reuse, and commonality through information sharing and communication throughout the M&S community. A large number of organizations and a significant degree of effort are involved throughout the Army in leveraging M&S technologies for the execution of Title 10 responsibilities. This site is intended as a guide and directory to information on these activities. Users can locate, access, and obtain M&S resources that support the TEMO, ACR, and RDA domains.

29. Other Simulation Sources.

a. A supplemental source of simulation support for OT&E is the Army Distributed Interactive Simulation (DIS) efforts. The current on-line portion of the DIS is SIMulator NETworks (SIMNET), the first simulation system to integrate large numbers of manned vehicle simulators on a computer network.

b. Battlefield Distributed Simulation-Developmental (BDS-D), the follow-on system for development applications, provides a simulation capability that allows experimentation with human system interaction in a fully represented battlefield environment.

c. The follow-on system for training is the Combined Arms Tactical Trainer (CATT). The first system to be acquired under the CATT program is the Close Combat Tactical Trainer (CCTT). The CCTT will incorporate a man-in- the-loop high-resolution combat training simulator, useful in simulating multi-system interactions in a nonlinear battlefield environment.

d. Both BDS-D and CATT have potential for developing and/or testing new doctrine and tactics associated with developmental systems. They can also be used to measure the contribution to system effectiveness of the human interaction with the developmental system.

e. The Army has established the Project Manager for Instrumentation, Targets and Threat Systems (PM-ITTS) as the RDA Domain Business Manager for engineering and engagement level threat simulators and simulations that support Army materiel developments. The Threat Systems Management Office (TSMO) is the directorate within PM, ITTS that accomplishes that mission. TSMO can provide advice on the integration and utilization of threat M&S in specific collaborative environments. TSMO can also provide validated, DIS and HLA certified, live, virtual, and/or constructive threat M&S and or threat simulation services through the TSMO "threat node."

f. The Threat Simulator/Simulation Program Plan (TSPP) is a process to identify and compile total Army requirements for threat material solutions, clearly articulate those needs, and champion those solutions through the Army Program Objective Memorandum process. The annual TSPP process is driven by an Integrated Product Team (IPT) chaired by the Army Materiel Command's (AMC's) Deputy Chief of Staff for Research, Development and Acquisition (DCS,RDA). The TSPP IPT compiles threat simulator/simulation needs and consolidates the needs into a 1 to n list. This 1 to n list becomes the priority for resourcing threat simulators and simulations. It is critical that each organization input their threat simulation needs into the TSPP process to help ensure that individual program manager funds, via PM-ITTS, rather than non-system specific threat simulations.

g. Joint Modeling and Simulation System (JMASS). JMASS is an open architecture, simulation support environment for model development. It provides a flexible simulation infrastructure that assists model developers, engineers, and analysts in the development of digital models, configuration and execution of simulations, and analysis of simulation results.

Section VII
Conclusion

The T&E and M&S communities continue to develop partnerships in support of the acquisition process. It is only through well developed, fully coordinated plans that our soldiers can be confident that the systems that are deployed to them are effective, suitable, and survivable.

Appendix A. Points of Contact Within the M&S and T&E Communities

A. Theater and above Level Force-on-Force Models - focuses on all force levels at echelons above corps. Includes multi-corps, regional and global M&S, e.g., Force Evaluation Model (FORCEM), Concepts Evaluation Model V (CEM VI), Force Analysis Simulation of Theater Administrative and Logistic Support (FASTALS), and Global Deployment Analysis System (GDAS).

POC: U.S. Army Center for Army Analysis
Research and Analysis Support Directorate
ATTN: CSCA-RS
(703) 806-5505
DSN: 656-5505

B. Corps and Division Level Force on Force Models - focuses on single and multi-division levels of operation with or without a supervising corps headquarters (e.g., EAGLE and Vector in Commander (VIC).

POC: U.S. Army TRADOC Analysis Command
Corps/Division Modeling and Analysis Operations Analysis Directorate Support Center
ATTN: ATRC-OAC, Fort Leavenworth, KS
(913) 684-2276
DSN: 552-2276

C. Brigade Task Force Level and Below Force on Force Models - focuses on combined arms forces and single functional elements as they are represented as integral parts of combined arms and services activities (e.g., Combined Arms and Support Task Force Evaluation (CASTFOREM); Janus(T), American Canadian Australian British Urban Game (ACABUG).

POC: U.S. Army TRADOC Analysis Command
Brigade/Battalion Modeling and Analysis Support Center
ATTN: ATRC-W, White Sands Missile Range, NM
(505) 678-1012
DSN: 258-1012

Appendix A. Points of Contact Within the M&S and T&E Communities (continued)

D. Engagement, Mission/Battle, and Theater/Campaign Models - focuses on a single weapons system or piece of equipment. May address one on one or one on many situations (e.g., Field Artillery Fire Support Model (TAFSM) now called FireSim^{XXI}, Simplified Artillery, Reliability Growth Model (SESAME), Projectile Effectiveness Model (ARTQUIK), GROUNDWARS, and NATO Reference Mobility Model).

POC: U.S. Army Materiel Systems Analysis Activity Special Studies and Activities Office
ATTN: AMXSY-DA
(410) 278-6576
DSN: 298-6576

E. System Level Weapon Systems Performance data for U.S. and threat systems and characteristics data for U.S. systems - data focuses on the lowest level system such as an air defense gun with its crew or a tank with its crew (includes reliability and supportability).

POC: U.S. Army Materiel Systems Analysis Activity Special Studies and Activities Office
ATTN: AMXSY-DA
(410) 278-6576
DSN: 298-6576

F. System Level Weapon Systems, operational and characteristic data for threat systems - focuses on the characteristics of lowest level threat system such as an air defense gun or tank.

POC: Office, Deputy Chief of Staff for Intelligence
HQDA (ODCSINT)
ATTN: DAMI-FIT
(703) 614-8121
DSN: 224-8121

G. Engineering and Engagement Level Threat Models/Simulations and Associated Threat Services – detailed M&S providing high fidelity representations of former Soviet Union, Peoples Republic of China, and 'gray market' threat systems and their components.

POC: Threat Systems Management Office
ATTN: AMSTI-ITTS-S (Chief, Business Development)
Redstone Arsenal, AL 35898
(256) 876-9656 X 206
DSN: 746-9656 X 206

H. Engineering/Hardware in the Loop Models - focuses on M&S that augment testing in various stages of the materiel acquisition process. Models and simulations are used in investigating mechanical, electrical, and physical phenomena associated with the functioning of an item system in an engineering sense (e.g., Dynamic Ground Target Simulator (DGTS), Dynamic Analysis and Design System (DADS), Wide Area Mine Sublet Simulation, Tow Weapon System, LOSA-T All Digital Six Degree-of-Freedom (6-DOF) Simulation Development and Test Simulation (DTSIM).

POC(s): U.S. Army Research, Development and Engineering (RD&E) Centers, U.S. Army Communications - Electronics Command
ATTN: AMSEL-RD-AED-MA
(908) 544-4682
DSN: 992-4682

U.S. Army Tank-Automotive Command
ATTN: AMSTA-RYA
(313) 574-8633
DSN: 786-8683

U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSMC-SA
(201) 724-5262
DSN: 880-5262

U.S. Army Aviation and Missile Command
ATTN: AMSMI-RD-SS
(205) 876-4271
DSN: 746-4271

U.S. Army Research Laboratory
(301) 394-4650
DSN: 290-4650

For PEO/PM managed systems it is common practice for the PEO or PM to sponsor contractor M&S development related to the T&E of their individual systems. For systems of interest contact the respective PEO/PM to determine the availability of M&S tools and their state of accreditation.

Appendix A. Points of Contact Within the M&S and T&E Communities (continued)

I. Vulnerability.

SLAD
U.S. Army Research Laboratory
ATTN: SLCBR-VL
(410) 278-1171
DSN: 298-2256

J. Technical Testing.

U.S. Army Test and Evaluation Command
ATTN: CSTE-PM
(703) 681-6818
DSN: 761-6818

U.S. Army Developmental Test Command
Technical Director
ATTN: CSTE-DTC-DC
(410) 278-1016
DSN: 298-1016

K. Operational Test.

U.S. Army Test and Evaluation Command
ATTN: CSTE-PM
(703) 681-6818
DSN: 761-6818

U.S. Army Operational Test Command
Technical Director
ATTN: CSTE-OTC-TD
(254) 288-1057
DSN: 738-1057

L. Evaluation.

U.S. Army Test and Evaluation Command
ATTN: CSTE-PM
(703) 681-6818
DSN: 761-6818

U.S. Army Evaluation Center
ATTN: CSTE-AEC
(703)681- 9872
DSN: 761-9872

M. Model-Test-Model.

U.S. Army TRADOC Analysis Command - WSMR
ATTN: ATRC-WMC
(505) 678-6016
DSN: 258-6016

U.S. Army Test and Evaluation Command
ATTN: CSTE-PM
(703) 681-6818
DSN: 761-6818

N. Man-in-the-loop Training Simulators.

U.S. Army Simulation, Training, and Instrumentation Command
ATTN: AMSTI-TD
(407) 380-4325
DSN: 960-4325

O. Threat Simulator/Simulation Program Plan (TSPP) – Process identifies and funds threat M&S products that can support more than one RDA development.

POC: Each Army Materiel Command Major Subordinate Command and each Program Executive Office has a TSPP Integrated Product Team Member. In many cases each Deputy for Systems Acquisition and each Research, Development, and Engineering Center has either a primary or alternate point of contact. A current listing can be obtained from the IPT Executive

Secretary (256) 876-9656 X206/ DSN: 746-9656 X206/Jeff_Langhout@stricom.army.mil.

P. VV&A of M&S.

HQDA
U.S. Army Modeling and Simulation Office
ATTN: DAMO-ZS
(703) 601-0009
DSN: 329-0009

Appendix B. Examples of Weapon Systems M&S Use.

A. STINGRAY Countermine. Another example of the use of M&S to augment STINGRAY test results involved the use of the Low Energy Laser Weapon Simulation (LELAWS). STINGRAY is intended to act as a countermeasure to landmine optical and electro-optical targeting systems. LELAWS is a simulation that estimates the probability that a given countermeasure was successful. In preparation for the STINGRAY Concept Demonstrator (CD) DT, LELAWS was used to estimate downrange laser energy. This information was used to determine STINGRAY CD test instrumentation/calibration requirements. As LELAWS was to be used in STINGRAY's AoA/COEA, the PM-STINGRAY authorized a number of test runs dedicated solely to supporting the validation of the LELAWS methodology. After the STINGRAY CD testing was completed and the test data applied to LELAWS validation, an accredited LELAWS was used to conduct a risk assessment on the STINGRAY's ability to meet user performance requirements in its next phase of development. The risk assessment was conducted by inputting near-term STINGRAY technology options into the LELAWS model, estimating STINGRAY performance using the validated LELAWS methodology, and comparing LELAWS output to STINGRAY user requirements.

B. Mine Systems

1. MINEMIX has and is being used to supplement T&E efforts related to the development and fielding of the Army's mine/barrier systems. The MINEMIX model is a Monte Carlo simulation structured to provide estimates of minefield effectiveness for various 'mixes' of both anti-personnel and anti-materiel mines. Conventional, scatterable, and SMART mines can be included in the layout of various minefields. The performance of individual mines is described by a collection of parameters that indicate: arming reliability, fuzing reliability, target vulnerability, probability of being a 'dud', countermeasure probability, etc. The model provides the capability of estimating the effectiveness of 'minefields' against target arrays that are constructed of different types and numbers of vehicles, e.g., main battle tanks, APCs, squad formations of personnel, and wheeled vehicles. The matrix of output produced by the model enables the user to depict the exact configuration of the minefield, along with a tally of the "killer/victims" (i.e., which mines defeated which targets).

2. In the context of T&E, MINEMIX has been used to supplement limited testing of the expensive Wide Area Mine (WAM). The effectiveness of the WAM is a function of the distance at which the mine detects and attempts to engage a valid target that enters its zone of authority. In order to address questions of minefield effectiveness, MINEMIX supplements the test data acquired at specific 'ranges' and allows the analyst to examine issues such as the requirement for range sensitivity, mine spacing, mine mixing with scatterable mines, etc., without additional test results. MINEMIX simulation output was used to assist in the formulation of valid requirement

parameters that became part of the approved WAM operational requirements document (ORD).

3. In terms of reducing testing, MINEMIX, coupled with other engineering simulations, can be used to fill voids left by the limited testing that is planned for the WAM system. For example, the effectiveness of WAM is also a function of the point on the target that is hit by the explosively formed penetrator. Captive flight tests of the sensor are used to build a database of 'hit points' for various launch conditions which then serve as an input array to the MINEMIX model to allow sensitivity studies concerning this key parameter. In addition to captive flight tests, various engineering simulations of the sensor/target encounter are also used to provide input to the MINEMIX model and to supplement 'live mine' testing against actual or surrogate targets.

C. Fire Support C3I Systems

1. Simulation/Stimulation (SIM/STIM) software is a real-time, multitasking system that provides two functions related to the T&E for the Army Field Artillery Tactical Data System (AFATDS) testbed. First, it simulates those nodes (units) in the Brigade slice that are not present within the given AFATDS system under test (SUT). First simulating messages that occur between simulated nodes and performing the actions of the simulated nodes with realistic timing accomplish this. Second, SIM/STIM stimulates the real equipment within the SUT by transmitting representative messages from the simulated nodes, as well as receiving and processing message traffic from the SUT.

2. SIM/STIM was first developed for use in AFATDS concept evaluation testing. Currently, SIM/STIM and its derivatives are being planned as an integral part of the Fire Support Automated Test System (FSATS) which is a suite of test instrumentation to be used to support test planning, test design, test execution, data reduction, data analysis, and test reporting associated with the DT and OT of the Army's fire support systems. Initially, FSATS is envisioned for use in the Post Production T&E and IOT&E of the AFATDS system.

D. PATRIOT Air Defense Artillery System. The PATRIOT Advanced Capability-3 (PAC-3) Program uses M&S to support the system throughout the life cycle across five functional areas: engineering development, combat development, T&E, training, and exercise support. PATRIOT M&S types include live, virtual and constructive. PATRIOT is developing and modifying several M&S to be Distributed Interactive Simulation (DIS), and High Language Architecture (HLA) compliant. These DIS/HLA M&S allow PATRIOT to accurately represent the system and interact with other systems during exercises and theater missile defense Family of Systems (FoS) Hardware-in-the-Loop Tests (HWILT) using a common threat provided by the Theater Missile Defense System Exerciser (TMDSE). This capability includes simulating environment, multiple simultaneous threats, debris, command, C2, jamming and other critical parameters.

1. PAC-2 Simulation (PAC2SIM). PAC2SIM contributes to the functional areas of engineering development and T&E. It is a constructive digital simulation tool that supports Milestones 0, I, II, and III for evaluating the performance of the pre-PAC-3 configurations. These configurations include the PAC-2/QRP system: Configurations 1 and 2 Standard, with Stand Off Jammer Capability (SOJC), and Configuration 3 with PAC-2 and GEM. PAC2SIM includes models of PATRIOT surveillance, engagement decision weapon assignment (EDWA), guidance, and lethality. The surveillance model is a probabilistic model designed to analyze the performance characteristics of the PATRIOT multifunction phased array radar surveillance function. Selected aspects of the actual system EDWA logic are included in the simulation.

a. PAC2SIM incorporates two major simulation components: PATRIOT Simulation (PATSIM) and Lethality End Game Simulation (LEGS). PATSIM contains the guidance 6 degree of freedom (6-DOF) and PATRIOT Surveillance Simulation (PASS) models. PATSIM, a Monte Carlo simulation, is designed primarily to evaluate the majority of scenarios, which the PAC-2 system is capable of engaging. Those engagements include ABT missions (clutter and / or jamming), interconnected fire platoon triangulation, TBM missions types "A" and "B", and SOJC missions. Each scenario primarily evaluates the performance of one missile versus one or more targets. PASS is a high fidelity model of the ground based radar surveillance operations.

(1) The guidance model is a 6–DOF simulation for evaluating the tactical guidance capability of Standard, SOJC, PAC-2 and GEM missiles against both non-TBM and TBM targets. The guidance model consists of the following major submodels: PATRIOT missile, non-TBM, and TBM targets, ground system, uplink/downlink, relative geometry, and environment. The lethality section models the missile/target kinematics, fuze/target interaction, warhead characteristics target vulnerability models, and the lethality computation for all pre-PAC-3 missiles. For each set of Monte Carlo samples from the guidance model a lethality prediction is produced for the fuze-warhead-target kill assessment.

(2) LEGS is a 6-DOF simulation used in conjunction with geometric and kinematics data from PATSIM to estimate lethality of the PATRIOT missiles versus various ABT or TBM threats. LEGS provides modeling of the fuze-target interactions, warhead characteristics, target vulnerability, missile-target kinematics, and lethality computations. TBM warheads modeled include high explosive, chemical, submunitions, and biological. Endgame geometry is input to LEGS from PATSIM and the user, via an initialization file, provides specifics of the endgame encounter. For each set of intercept points provided from the guidance simulation, LEGS provides a lethality prediction for the fuze-warhead-target kill assessment, categorizing the elements of kill into blast, fragment, or direct hit. It also summarizes damage to the target and provides the summary to the user via various output files.

b. PAC2SIM contributes to cost savings through reduction of actual flight tests (and some ground tests). Proposed design changes to the system are modeled and implemented, the simulation is run, and results are analyzed and documented. Time and effort are saved as system/missile performance, or design changes, can be evaluated in a non-flight environment.

c. V&V for PAC2SIM is ongoing for the two major components of the simulation: PATSIM and LEGS. These components were accredited in 1993 for the PAC-3 COEA DAB Decision. PAC2SIM will be accredited by ATEC to support MS III.

2. PAC-3 Simulation (PAC3SIM). PAC3SIM contributes to the functional areas of engineering development, combat development, and T&E. It is a constructive digital simulation tool that is used to demonstrate compliance with the majority of the system performance related requirements and supports Milestone III. The requirements that PAC3SIM will be used to demonstrate are primarily the probability of kill (Pk) and defended area. It simulates all aspects of a PATRIOT engagement with a PAC-3 missile from system emplacement through lethality assessment. PAC3SIM simulates one-on-one engagements that include the radar (PASS), missile system/subsystem simulation (SSS), non-TBM threat lethality (Enhanced Lethality End-Game Simulation (ELEGS)), the ground model, and TBM lethality (Parametric Endo/Exo Lethality Simulation (PEELS)). The simulation supports a variety of activities including: development of subsystem hardware requirements, guidance law / algorithm development and evaluation, pre-flight predictions, and post-flight reconstruction.

a. The major focus of PAC3SIM is the assessment of PAC-3 system performance when engaging a threat with a PAC-3 missile. The most meaningful output of the PAC3SIM is the single shot engagement kill probability (SSEKP), given that no missile reliability failures occur. The simulation is then run over the engagement zone to determine the defended area on the ground for the required Pk with intercepts above the specified keepout altitude.

b. PAC3SIM combines several models to form the highest fidelity end-to-end simulation of the PAC-3 system. These models are ground system model, missile model, target models, and the lethality model.

(1) The Ground Model is made up of three major components: the PATRIOT radar surveillance and tracking modes, the enhanced weapons control computer performing the engagement decision weapon assignment function, and the FSC performing the calculations and scheduling uplinks to the missile. Other components of the simulation model are: the radar uplink/downlink process, missile track provided by the uplink/downlink, the emplacement process, ICC triangulation and cueing, and the launching station.

(2) The Missile Model contains models of all the subsystems of the PAC-3 Missile including the seeker, attitude control motor section, guidance processor unit, inertial measurement unit, radio frequency data link, lethality enhancer, the solid rocket motor, and the

aerodynamic maneuvering system. Additionally, it contains the 6-DOF equations of motion, missile mass properties, and detailed aerodynamics and jet interaction databases and is used to model all modes of guidance and navigation through all phases of flight.

(3) The Target Models in PAC3SIM include the TBM and non-TBM threats. TBM target models, which are provided by the Missile Space Intelligence Center (MSIC), consist of digital data files of the trajectory and the C and Ka band radar cross section signature information. Non-TBM target models also include the C and Ka band RCS signature information. The non-TBM flight profile is input to the simulation as a velocity, altitude of flight, heading, and maneuver history.

(4) The Lethality Model consists of the PEELS model for TBMs and the ELEGS model for non-TBM lethality calculations. PEELS code uses the missile and target positions and orientations at the point of closest approach to calculate the damage to the target by the encounter. The model has the capability to represent unitary high explosive, bulk chemical, high explosive and chemical submunition, agents of biological origin, and nuclear TBM warhead types. TBM target descriptions are provided by MSIC. ELEGS code uses the missile, lethality enhancer fragments, and target positions and orientations at the point of closest approach to calculate damage done to the target by the encounter. ELEGS also includes the vulnerability model of various fighter aircraft and cruise missiles.

c. PAC3SIM contributes to cost savings through reduction of actual flight tests (and some ground tests). Proposed design changes to the system are modeled and implemented, the simulation is run, and results are analyzed and documented. Time, cost and effort are saved as system/missile performance can be assessed prior to fabrication and test.

d. An extensive V&V program for PAC3SIM is being conducted by a sub-IPT. PAC3SIM will be accredited by OPTEC for the purpose of supporting performance estimates for independent evaluation during the PAC-3 Missile LRIP and MSIII decisions. These activities conform to Department of Defense (DOD) Directive 5000.59, DOD Modeling and Simulation (M&S) Management, Army Regulation AR 5-11, Army Model and Simulation Management Program, and Department of the Army Pamphlet (DA PAM) 5-11, Verification, Validation, and Accreditation of Army Models and Simulations.

3. Multi-Function Simulation (MFSIM). The MFSIM simulation contributes to the functional areas of engineering development, T&E, and exercise support. It is a constructive digital simulation tool used to demonstrate compliance with the traffic handling, multiple simultaneous engagement, and multi-function requirements of the system and supports Milestone III. It simulates, in great detail, the scheduling and utilization of the PATRIOT radar resources. The simulation models the target kinematics, missile flight, and target track errors at a fidelity that is sufficient to properly drive the scheduling and utilization of the radar resources (time

power budget).

a. MFSIM simulates surveillance functions including: use of the system defined search waveforms, frame times, detection ranges, environmental actions, and validation actions. The surveillance model includes detailed models of both the search and track functions of the radar. Search is modeled for the full search raster in both the non-TBM and TBM modes of operation. The priority of each sector is maintained and waveform selection is performed as a function of sector, chaff, and weather conditions. The search detection logic accounts for both quiet and jamming targets. System noise figure curves, losses, and processing gains are included in the modeling. Track logic includes the full validation and track initiation sequences. Track maintenance is established as a function of range, identity, and EDWA priority. The track waveforms and rates are modeled with logic to account for missed track actions and track drops. Saturation alleviation logic is included to accurately provide loading data.

b. The guidance and EDWA functions modeled in MFSIM represent only those functions that affect radar loading and the multifunction capability of the system. Target evaluation is modeled to provide target identity and determine threat. The weapon assignment function is modeled to reserve missiles and launchers for engagements as well as launch commands. The To-Be-Engaged Queue is also modeled to prioritize engagement.

c. MFSIM contains a very detailed model of the PATRIOT radar scheduler. All radar actions are scheduled according to priority and all scheduling constraints such as the guidance template, fast Fourier transform scheduling, duty cycle, and antenna switching rate are included. The scheduler places all radar action requests for the next major cycle interval into the appropriate queue: scheduled request queue (search and track) or unscheduled request queue.

d. Outputs of MFSIM provide a means of performing accurate evaluations of the PATRIOT search, track, and engagement capabilities. These outputs include: the number of intercept conditions, dropped tracks, number of targets under track, unengaged hostile targets that penetrate due to radar loading, plots of radar loading per major cycle interval, and average search rates achieved.

e. MFSIM contributes to cost savings by providing a cost efficient method for evaluating system multifunction performance in a multiple simultaneous engagement (MSE) environment. Proposed changes to the radar, such as the requirement to increase tracking capacity, have alternative design possibilities that are "checked out" through the simulation for system effectiveness and difficulty of implementation.

f. MFSIM V&V of the PDB - 4 capability has been completed. An initial presentation to AMSAA and AEC was made in November 1996. A sub-IPT exists for the purpose of developing and executing a detailed plan for V&V. Future validation will be accomplished by comparing MFSIM results with the results from scenarios scripted and executed on the Flight Mission Simulator (FMS). These scenarios will be used to verify the model's ability to adequately simulate the PATRIOT radar system in both light and heavy target load environments. MFSIM PDB - 5 version will be accredited by OPTEC to support use of performance estimates under heavy load conditions for the independent evaluation of the PAC-3 System for MSIII. This version of MFSIM will include complete models of all PAC-3 Growth Programs, which affect radar loading. These activities conform to Department of Defense (DOD) Directive 5000.59, DOD Modeling and Simulation (M&S) Management, Army Regulation AR 5-11, Army Model and Simulation Management Program, and Army Pamphlet PAM 5-11, Verification, Validation, and Accreditation of Army Models and Simulations.

4. Flight Mission Simulator (FMS). The FMS simulation contributes to the functional areas of engineering development, T&E, and exercise support. It is a virtual HWIL simulation tool that supports Milestones 0, I, II, and III and is a real-time system exerciser used to evaluate PATRIOT performance against specified threats. Users of FMS script and load one or more tactical scenarios into the simulator to electronically "engage" PATRIOT tactical hardware and software against simulated multiple non-TBM and TBM threats simultaneously. The FMS simulates non-TBMs and TBMs for the PATRIOT system by injecting radio frequency target waveforms into the radar receivers "front end." Tactical hardware and software respond accordingly and system performance is evaluated. Simulations using FMS can be viewed as being composed of two distinct parts: (1) the FMS, which simulates radio frequency (RF) target waveforms, electronic countermeasures (ECM), PATRIOT missiles, and the PATRIOT launcher and (2) PATRIOT tactical hardware and software that consist of the RS and ECS, with radar resident software (RRS), EWCC, and FSC.

a. A simulated FMS engagement begins with a scripted scenario that is defined by the user, which can include both real and simulated targets. The scenario is loaded into the Simulation Control Computer (SCC) located within the Test Control Computer. The simulation is controlled by reading radar action messages sent by the ECS EWCC to the radar via the non-tactical FMS message junction box. The EWCC commands the radar to point the antenna in a specific direction. The SCC in the FMS will determine if the target is located in the radar beam and generate the appropriate response to be injected into the radar (waveform, signal levels, time of injection). If the scenario calls for ECM, the SCC directs the addition of the appropriate jamming to the simulated environment. Any of the "detected" targets in the scenario will be designated and displayed with the proper symbology depending on their classification: friendly, hostile, or unknown.

b. Intended uses of FMS include evaluating PATRIOT system performance under maximum target load conditions, evaluating ECM techniques against the surveillance function, and testing PAC-3 system modification (e.g., operational hardware and software as well as radar hardware and radar resident software). FMS will be used in support of CDI-3, Radio Logic

Communication Enhancements Upgrade, and PAC-3 system integration, checkout, and testing at WSMR, at Bedford, Massachusetts, and at each Initial Operational Test and Evaluation test site. It will also be used to support pre-flight prediction and post-test performance assessment and analysis, system-level testing (with/without radiation during field testing), post deployment comprehensive testing, production qualification testing, and all engineering investigations. In addition the FMS will be used in end-to-end HWIL testing as the first leg of a two phase HWIL test involving the MICOM Millimeter Wave Simulation System (MSS-2) facility.

c. Using FMS and MSS-2 facility hardware in end-to-end simulation draws upon the strengths of each simulation. FMS simulates MSE but is not HWIL robust. The MSS-2 facility is HWIL robust for end game but simulates only one-on-one engagements. The conditions of a pre-determined engagement are captured from the FMS test and transferred, in non-real time, to the MSS-2 facility. Then MSS-2 completes the end game simulation.

d. FMS is instrumental in speeding the introduction of PATRIOT systems and PAC-2 and PAC-3 improvements into the inventory. Hardware and software "problems" which might not otherwise be detected until actual testing are diagnosed and corrected early in the design stage. Additionally, FMS prevents costly program delays by real-time testing of all hardware / software (except the antenna) at the developer's site, prior to shipment to the missile test site.

e. V&V for the FMS will be conducted through the IPT process. A VV&A Working Group has been established under the FMS IPT to provide oversight and management. FMS IPT membership includes the developer, PATRIOT system integration contractor, the PAC-3 Missile Segment contractor and independent government agencies from the testing community. Because FMS has a long history of usage during operational and development testing, the FMS V&V plan capitalizes on this past usage of the FMS in the VV&A process. The VV&A process will focus on FMS hardware and software upgrades in support of the PAC-3 system. FMS will be accredited by ATEC. ATEC will also accredit FMS for use as a system stimulator during Concept Development Test and Evaluation, Initial Operational Test and Evaluation and Follow-on Operational Test and Evaluation.

5. Guidance Test Simulation Facility (GTSF): GTSF contributes to the functional areas of engineering development and T&E. It is a live and constructive HWIL simulation tool that supports Milestones 0, I, II, and III and provides full guidance simulation capability for the PATRIOT system. This capability simulates emplacement, search/track, engagement decision weapon assignment, missile launch, midcourse flyout, and terminal guidance.

a. GTSF allows a checkout of the integration of the PAC-3 missile to the PATRIOT ground system hardware before actual testing at a test range is accomplished. It integrates all hardware that runs tactical software into a single facility. For the pre-PAC-3 missile segment the GTSF includes the following hardware: missile seeker, EWCC, uplink message transmission and downlink message receiver, and a subset of the ground radar equipment. For the PAC-3 Missile Segment the GTSF configuration includes: Phase III Radar with CDI-3 upgrades, EWCC, FSC, the ELES, missile guidance processor unit, seeker data processor, gimbal processor, and radio frequency downlink.

b. The radar model in the GTSF has been updated to add additional target capability as well as a second missile capability. CDI-3 waveforms have been added to accommodate testing of discrimination processes.

c. V&V has been accomplished several times in the past for the pre-PAC3 functionality of the GTSF. The baseline GTSF facility was validated as part of the PATRIOT program in accordance with Validation Plan BR-7867-2 and documented in accordance with Validation Report BR-11930. A rigorous configuration management system is maintained for both the simulation code and facility hardware to ensure continued integrity of the simulation data. A large part of the PAC-3 GTSF will use existing hardware and software that has been verified through other activities. Performance data for these existing models (pre-PAC-3) are available in the GTSF and will be used during the V&V phase of the PAC-3 GTSF upgrade task in order to minimize the resources needed. This will allow the V&V activity to focus on evaluation of those models and equipment that are unique to PAC-3. The V&V will conform to DOD Directive 5000.59, DOD Modeling and Simulation (M&S) Management, Army Regulation AR 5-11, Army Model and Simulation Management Program, DA PAM 5-11 - Verification, Validation and Accreditation of Army Models and Simulations. The V&V Process will be very similar to the PAC3SIM and MSS-2 V&V process.

6. Millimeter Wave Simulation System – 2 (MSS-2): The MSS-2 simulation contributes to the functional areas: engineering development, combat development, and test and evaluation. It is a constructive HWIL simulation tool that supports Milestone III. RDEC, Redstone Arsenal, MSS-2 HWIL simulation provides guidance simulation capabilities to include the support of performance assessment of active terminal seeker guidance functions in a dynamic flight environment. MSS-2 allows missile design optimization over a wide range of engagement scenarios to ensure all missile performance criteria are met. It provides a unique capability of simulating complex RF environments, which may be used in development of critical seeker software such as electronic counter-countermeasures (ECCM). Considering end-to-end risk reduction, MSS-2 allows in-depth analysis of PAC-3 missile functions through simulation and missile telemetry outputs during each engagement. Critical function variables will be telemetered and recorded to allow for analysis of missile performance during the simulated engagement and to allow for comparison with live missile firings to ensure MSS-2 accurately predicts missile flight performance. Therefore, once validated with missile flight test data, the simulation can be used to provide an extensive amount of data to decision makers to increase the confidence level that the PAC-3 missile will meet its operational and technical requirements.

a. MSS-2 will be used as a primary tool in support of the EMD program to address whether the PAC-3 missile meets required exit criteria prior to LRIP. Critical Technical Parameters (CTPs) addressed by MSS-2 are: PAC-3 missile SSEKP against TBM and ABT targets and system survivability against the ARM threat. Critical Operational Issues and Criteria (COIC) addressed by MSS-2 include ORD compliance for TBM and ABT defense and compliance against RSTA/SOJ and ARM threats.

b. The MSS-2 HWIL simulation contributes to cost savings by reducing the number of live missile firings. The simulation evaluates the missile design over a wide range of engagement scenarios and environments in a laboratory setting. Due to the Monte Carlo nature of the simulation, it provides a large number of samples for each intercept as opposed to the sample size of one from a live missile firing.

c. An extensive V&V program for the MSS-2 simulation is on going. The V&V will conform to DOD Directive 5000.59, DOD Modeling and Simulation (M&S) Management, AR 5-11, Army Model and Simulation Management Program, and DA PAM 5-11, Verification, Validation and Accreditation of Army Models and Simulations. The V&V Process will closely follow the PAC3SIM V&V process. MSS-2 will be accredited by OPTEC to support use of performance estimates in the independent evaluation for the potential to satisfy ORD requirements for the PAC-3 Missile LRIP decision and for end game evaluation during Initial Operational Test and Evaluation in support of MS III.

7. Flight Mission Simulator-Digital (FMS-D): The FMS-D is a digital, medium fidelity PATRIOT system radar, launcher and missile simulation developed in conjunction with PATRIOT tactical software. FMS-D contributes to the test and evaluation, training and exercise support. The FMS-D provides the capability to directly drive a tactical PATRIOT ECS with scenario truth data from the TMDSE. The FMS-D is DIS compliant with plans to upgrade to HLA. This PATRIOT segment driver is a key component of the FoS HWILT environment.

8. Extended Air Defense Simulation (EADSIM): The EADSIM simulation contributes to the functional area of combat development. It is a constructive digital simulation tool that supports COEA type analyses. As a force-on-force system effectiveness simulation it evaluates the effectiveness of various battle management / command, control, communications and intelligence (BM/C3I) nodes, theater missile defense (TMD) air defense architectures, and weapons systems in a full battlefield environment. It provides an analytic model of air and missile warfare used for scenarios ranging from few-on-few to many-on-many.

a. EADSIM continues to be utilized and a baseline of PATRIOT maintained, throughout the life cycle, to supplement force on force studies and/or FoS effectiveness analysis, and for verification of other Air Defense community studies playing PATRIOT to ensure accurate representation.

b. Output of EADSIM, however, clearly demonstrates those changes that have positive or adverse effects on PATRIOT system effectiveness and / or upon interoperability of PATRIOT with other systems. This benefit of EADSIM precludes changes to the system, which would be technically or doctrinally inappropriate.

9. Defense Design System Exerciser (DDSE): The DDSE simulation contributes to the functional areas of engineering development, combat development, test and evaluation, training, and exercise support. It is a constructive digital simulation tool that will support Milestone III. DDSE is used to quantify radar and system loading as a function of threat activities and to assess the impact of tailoring the PAC-3 radar in order to free up radar resources in a threat rich environment. It is also used to assess the effectiveness of the PATRIOT battalion or an air and missile defense task force, including Theater High Altitude Area Defense (THAAD), against a threat comprised of ABTs, TBMs, Stand Off Jammers (SOJs), and cruise missiles. It serves as a commander's tool to develop and assess a defense plan that best performs the mission orders being executed.

a. DDSE is housed in the Tactical Control System (TCS) as PATRIOT tactical equipment. It receives input defense designs from Tactical Planner including: defended assets, threat locations, blue assets (including THAAD interoperability), primary target line orientations, and radar intervisibility coverage. The simulation then "plays the war" providing an evaluation of defense design effectiveness against the expected threats. Deployment planning can be set up in DDSE by placing radar sites and analyzing/evaluating communications links. Post processing provides statistics relating to the number of engagements above and below the keepout altitude and usage of main array phase shift elements relative to specified threat target elevation sectors.

b. DDSE is being developed to provide the soldier a method of exercising defense designs generated with the Tactical Planner as a part of the Tactical Control System and to represent PATRIOT in a DIS environment.

c. Prior to Roving Sands 97 DDSE was accredited as DIS compliant in accord with IEEE Standard 1278.3 (2.04) protocol for acceptance into the exercise. The PATRIOT Project Office is aware of the HLA requirements and has identified certain M&S for HLA compliance and others for waiver.

M&S will continue to be critical in all program phases to verify system performance prior to critical program decisions and to support production qualification testing, engineering investigations, and post-deployment comprehensive testing. Contribution of PATRIOT M&S to end-to-end risk reduction activities will provide an extensive amount of data to decision makers to increase the confidence level that the PAC-3 missile will meet its operational and technical requirements.

Appendix C. Other T&E-Related Uses of M&S

It is impossible to address all the possible or even likely uses of M&S within the T&E process. Test requirements span a wide spectrum of conditions and are seldom standardized. There are, however, three areas in which the analytical community and M&S can significantly aid T&E:

1. Crew training analyses/evaluations and tactics and operational techniques development
2. Test planning and operational scenario development
3. Data extrapolation/interpolation beyond test results (See Appendix C, paragraph 3.b).

These M&S applications can supplement T&E and provide a much more robust and informative system evaluation. The following concepts and examples are intended to characterize basic principles and processes.

1. Crew Training Analyses/Evaluations

a. Operational testers have become involved in training and training development through Force Development Test or Experimentation (FDT/E). The implementation of the FDT/E process stemmed from an identified need for more comprehensive training of units prior to operational testing. Insights gained from several operational tests (Ml tank, AH-64A and OH-58D helicopters) indicate that modern weapon systems require comprehensive tactics and operational techniques development to fully exploit weapon system improvements. For these tests, field training was required to fully develop operator skills. It is envisioned that training demands on resources and test facilities will continue as next generation aircraft, armored systems and command and control systems are tested. Multifunction systems will task the limits of operators during operational testing.

b. In addition to using models to aid training, they are inherent in the Training-Modeling Integration (T-MI) methodology that uses test data and modeling to evaluate crew and individual performance during conduct of the test. Crew evaluation requirements are not isolated to only FDT/E. All types of operational testing require crew performance evaluation. The T-MI methodology was developed within the U.S. Army Training and Doctrine Command (TRADOC) for the investigation and development of crew and individual training information. M/S is used to develop training scenarios, performance standards, and task workload information. T-MI has application in addressing weapon system crew training requirements as well as real time crew performance evaluations during operational testing.

c. Training and crew performance analyses need detailed data that identify when a specific event occurred (time tagged data). High-resolution simulations producing detailed time related history files provide an excellent source for these types of analyses. CASTFOREM (battalion/task force level model) is one of the current models used by TRADOC that produces comprehensive time related history file information. More aggregated low-resolution simulations are less useful for training analysis.

2. Tactics, Techniques, and Procedures (TTP) Development. Use of M&S to aid in the development or refinement of tactics and operational techniques and procedures differs from their use in individual training because the two analytical processes often require different simulation tools. The interactive, man in the loop, high-resolution simulation is a tool used for the development of tactics and operational techniques. JANUS, for example, has been used widely for this application. The tester can benefit significantly from insights gained in the use of M&S to examine tactics and operational techniques. Test design scenarios can be reviewed in advance in order to better understand weapon system tactics and techniques. It benefits the entire testing process if effective and well-defined tactics are developed prior to beginning the test.

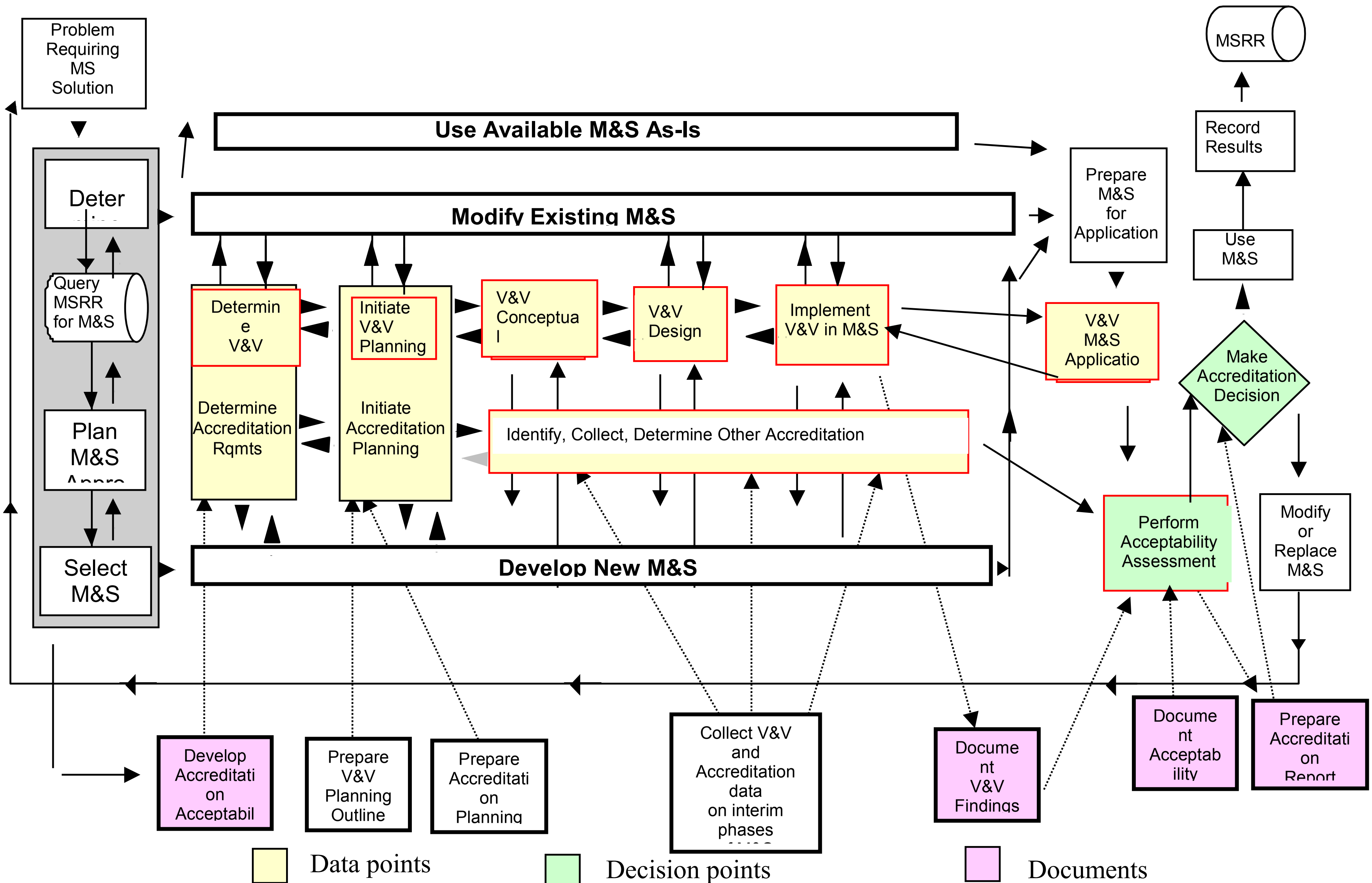
3. Data Extrapolation/Interpolation.

a. Modeling may be a cost effective supplement to operational testing when test limitations and constraints are significant. In order to use M&S data for evaluation of a system under conditions differing from the actual test, it is essential that M&S results and test results be compared to determine the appropriate calibration effort. Calibration is a careful and intuitive model/simulation modification process in order to correlate model output and test results. Calibration should be undertaken with caution. Changing model parameters to achieve high correlations is only prudent if the changed parameters are logical and address intuitively correct deviations from established algorithms. The model accreditation process will address calibration. The process will require identification of model parameter changes and the rationale, for such changes.

b. Tester and evaluator, using an accredited model, have an opportunity to augment or supplement field test results with modeled results. Interpolation can take the form of expanding sample sizes for trials that were difficult or expensive to perform. Extrapolation can take the form of selecting different terrain or employing larger forces. Extrapolation should be used with caution when estimating parameters for answering criteria. Extrapolation is valuable for investigation of trends or gaining insights into other areas of investigation. System evaluation must ultimately be based upon empirical evidence, objectivity, and military judgment.

Appendix D. Integrating VV&A into the M&S Life Cycle Management Process

Integrating VV&A in M&S Process



April 18, 2000

This page intentionally left blank.

DEPARTMENT OF THE ARMY
DEPUTY UNDER SECRETARY OF THE ARMY
OPERATIONS RESEARCH
102 ARMY PENTAGON
WASHINGTON DC 20310-0102

17 MAR 2000

MEMORANDUM FOR SEE DISTRIBUTION

SUBJECT: Army Guidelines on the Use of Models and Simulations (M&S) in Support of Test and Evaluation (T&E)

As a result of the Project Manager and Test Community Interaction Process Action Team (PAT) that I formed last year, eleven of the thirty recommendations developed were selected for implementation.

Enclosed are the subject guidelines that I hereby provide for your use. I encourage each of you to widely distribute these guidelines within your organization. A copy of the guidelines can be obtained from the U.S. Army Test and Evaluation Management Agency web site - http://www.hqda.army.mil/tema.

Walter W. Hollis

Encl

Walter W. Hollis
Deputy Under Secretary of the Army
(Operations Research)

DISTRIBUTION:
Commander, U.S. Army Materiel Command, ATTN: AMCRDA, 5001 Eisenhower Avenue, Alexandria, VA 22333-0001
Commander, U.S. Army Space and Missile Defense Command, ATTN: SMDC-SP-I, Box 15280, Arlington, VA 22215-0280
Deputy Commander, U.S. Army Space and Missile Defense Command, ATTN: SMDC-RM/SMDC-KMR, Box 1500, Huntsville, AL 35807-3801
Program Executive Officer, Air and Missile Defense, 215 Wynn Drive, Huntsville, AL 35805-3402
Program Executive Officer, Aviation, Bldg 5681, Room 160, Redstone Arsenal, AL 35898-5000
Program Executive Officer, Command, Control and Communications Systems, Myer Center, Room 3C109, Fort Monmouth, NJ 07703-5000
Program Executive Officer, Ground Combat and Support Systems, Bldg 171, Picatinny Arsenal, NJ 07806-5000

Program Executive Officer, Ground Combat and Support Systems, 6305 Eleven Mile Road, Warren, MI 48397-5000
Program Executive Officer, Intelligence, Electronic Warfare and Sensors, Myer Center, Room 3D121, Fort Monmouth, NJ 07703-5000
Program Executive Officer, Standard Army Management Information Systems, 9350 Hall Road, Suite 142, Fort Belvoir, VA 22060-5526
Program Executive Officer, Tactical Missiles, Bldg 5250, Room A200, Redstone Arsenal, AL 35898-8000
Project Manager, Instrumentation, Targets, and Threat Simulators, 12350 Research Parkway, Orlando, FL 32826-3276
Project Manager, Instrumentation, Targets, and Threat Simulators, National Capital Region Liaison, 13873 Park Center Road, Suite 500, Herndon, VA 20171

CF:
Commander, U.S. Army Test and Evaluation Command, ATTN: CSTE-CG CSTE-PM, Park Center IV, 4501 Ford Ave., Alexandria, VA 22302-1458
Director, Army Materiel Systems Analysis Activity, ATTN: AMXSY-B/AMXSY-S, 392 Hopkins Road, Aberdeen Proving Ground, MD 21005-5071
Director, Army Research Laboratory, ATTN: AMSRL-SL, Aberdeen Proving Ground, MD 21005-5068